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CORROSION TRACKING AND PREDICTION FOR C-141A AIRCRAFT MAINTENANCE SCHEDULING

APRIL 1978

TECHNICAL REPORT
FINAL REPORT FOR PERIOD SEPTEMBER 1975-OCTOBER 1977

Approved for public release; distribution unlimited

AIR FORCE MATERIALS LABORATORY
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Analysis of corrosion maintenance and utilization histories of C-141A aircraft has shown that these records can be used to develop a corrosion-prediction model. Exploitation of such a model could result in better efficiency in the use of aircraft, maintenance facilities, and manpower, since corrosion maintenance could be scheduled at the optimum time with respect to repairability, need, and available resources.

The USAF Maintenance Data Collection System does not generate sufficiently accurate and consistent records, however, to base a prediction model on

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existing data. A number of changes to the System would improve the quality of the data sufficiently so that an effective model could be developed. Potential cost benefits are far larger than those needed to effect the changes, hence the recommended changes should be implemented at an early date.

FORWORD

This is the Final Report for USAF Aeronautical Systems Division Contract No. F33615-75-C-5284 with Michigan State University. The Program described was initiated by the Principal Investigator when he was a National Research Council Senior Research Associate with Dr. C. T. Lynch at the Air Force Materials Laboratory in 1974-75.

The work that was done under this contract is one step in the evolution of a new and very promising approach to the problem of corrosion control and maintenance in complex systems. Although much remains to be done, it is clear now that this approach will have significant impact in the fight for corrosion cost-containment and reduction.

I am grateful to the National Research Council and to Dr. Lynch for providing the opportunity to develop this program. I also thank William Egan, Col., and Louis Setter, Col. (Ret.), USAF for their encouragement and support. Several individuals have contributed their efforts to the project in a variety of ways, particularly, Harold Beasley, Col., Garth Cooke, Lt. Col., William Richardson, Richard Fortin, and Ad Mohr, of Robins AFB; Perry Cockerham, Wright-Patterson AFB; Professor D. J. Montgomery, Richard Suter, Sue Emery, John Dreystadt, and Irving Shaefer, of Michigan State University; and K. Augustyne of Adaptronics, Inc. A number of people in the Military Airlift Command were of much help at one phase, and they are acknowledged separetly on pages 224-225.

Finally, I thank Michelle Ward for her patient preparation of this manuscript.

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SECTION 1
INTRODUCTION

Environmentally accelerated degradation and equipment failure are major problems in the maintenance of aerospace systems. Atmospheric-borne agents, such as water, salt, particulate matter, and pollutants, of course, are the proximate causes of such degradation. Although it is almost folklore knowledge that greater damage is experienced in saltwater environments, relatively little quantitative information exists which relates environmental conditions with environmentally-caused damage, despite efforts to assemble such data (1).

Predicting corrosion damage from exposure to corrosive environments may be approached from several directions:

1) A thorough knowledge of all characteristics of a metal (composition, microstructure, etc.), its potential and the mechanism whereby it corrodes, and the corrosive elements in the environment will provide a basis for prediction. This amounts to nothing less than completely understanding the nature of corrosion, a goal that corrosion scientists have worked toward for many years. It remains as far away as ever, as complexities multiply and new alloys are developed. One could hope to predict the behavior of a single alloy in a given environment, but the situation of a large collection of alloys in many environments would be hopelessly complicated.

2) Exposure of test samples to actual environments and cataloging the corrodibility provides a designer's guide in alloy selection and application (2), and to some extent one can anticipate corrosion damage from such data. In many cases,

however, the service environment turns out to be different from that expected or it may be one that has not been cataloged. Information on new alloys is unavailable and may take considerable time to gather. Finally, it appears difficult to correlate actual damage results with causative environmental factors (3).

3. Accelerated tests are used to obtain corrosion data in a shorter time and there are several standard tests in use (4). Unfortunately the results of such tests often do not correlate well with the damage inflicted by in-service exposure of test samples (3). This probably results because the corrosive agents and the mechanisms are not understood well enough to permit establishing a realistic environment for accelerated testing. Both environmental exposure and accelerated testing could provide the tools to predict damage to specific alloys but not for a complete system such as an aircraft.

4. Environmental exposure of a complete system and statistical analysis of corrosion damage vs. the environmental factors could be used to predict future damage and possibly determine cause-effect relationships. The present study is an effort of this type. It will be recognized that the first and fourth approaches represent opposite extremes.

"Environment" may be considered to include all factors which affect aircraft maintenance. These factors can be subdivided (after Moore (5)) into three major categories:

-environmental factors, in a traditional sense,
-operational factors,
-miscellaneous.

These categories are illustrated in more detail in Table I. Traditional environmental factors are moisture (as rain, snow, hail, condensation, humidity), atmospheric pollutants (sulfur dioxide, nitrogen oxides, ozone, sand, dust, salt, other particulates), wind, and solar radiation. Most of these, except solar radiation, would be most damaging to aircraft while on or near the ground--where military aircraft spend the bulk of their time, contrasted with commercial aircraft. Operational factors relate to utilization of the aircraft: flying hours, payload, altitude, mission profile, even pilot skill or the general tidiness of flight crews. Miscellaneous factors include such items as Technical Order Compliance, accidents, and design problems.

To the list of causes that contribute to environmental degradation, we would add the quality and effectiveness of housekeeping and preventive maintenance. It is not clear which of the three categories would be appropriate; perhaps this factor merits one of its own.

"Environmental degradation" covers a variety of problems, including corrosion, stress-corrosion cracking, and more. Throughout this report we use the term "corrosion" to include all of these, although such usage occasionally leads to argument.

The extent of corrosion damage, and hence the need for maintenance and repair, vary widely from one aircraft to another. These variations are most visible at depot maintenance, where nearly-identical aircraft-in terms of age, flying hours, and other traditional indexes of wear-are observed to be strikingly different with respect to corrosion (6).

TABLE 1.
CAUSES OF AIRCRAFT MAINTENANCE

MAINTENANCE-ROUTINE SERVICE
PREVENTIVE MAINTENANCE
REPAIR OF DAMAGE

MISCELLANEOUS	OPERATIONAL FACTORS	ENVIRONMENTAL FACTORS
-Faulty Design	-Sorties	-Pollution
-Accidents	-Airborne Vibration	-Wind
-T. Compliance	-Operating Hours	-Temperatures
	-Sortie Length	-Moisture
	-Other	-Salt Water
		-Sand and Dust

If the factors which cause such variations can be identified, significant improvements and cost reductions could be effected in corrosion maintenance:

- Corrosion maintenance requirements at both field and depot levels could be predicted for individual aircraft.
- Depot maintenance and inspection scheduling could be optimized with respect to damage and repairability.
- Manpower levels for corrosion control and maintenance could be matched more closely to need.
- Damage could be minimized by reducing the exposure to the most harmful environmental factors.

One might imagine that completely reliable cause-effect relations could be developed, yet such thorough knowledge is not necessary to achieve useful results. With the Air Force costs of corrosion maintenance exceeding one-half billion dollars annually, even relatively small improvements can save substantial sums.

The Air Force has considered several approaches to this task. One is a two-pronged program to establish a corrosion-severity index for each operational airbase (code-named "Pacer-Lime"), and another is a Corrosion Tracking and Prediction (CTAP) program on the C-130 aircraft force. The latter evolved essentially into the rationale for this study.

Pacer Lime employs two methodologies. (1) An *a priori* calculation of a numerical index which combines the commonly-measured weather factors. The computed index is not assumed to measure the corrosivity of an environment, but merely represents a composite of factors (e.g., humidity) believed to contribute to corrosion. (2) An experimental determination of environmental severity from corrosion damage on test coupons

fixed to outdoor exposure racks at each base. The experimental data would be used to calibrate the computed index.

The C-130 Corrosion Tracking and Prediction (CTAP) program would track the general corrosion posture of each C-130 aircraft in the USAF inventory and use this tracked posture to predict the most economic corrosion treatment intervals. A corrosion index would be computed for each aircraft, which would represent the cumulative percent deterioration of the corrosion-protective systems. These would be computed on a quarter-year time basis and would be related mathematically to: (a) An environmental corrosion-accelerator factor which would account for different climatic environments of the several operational bases; (b) a corrosion-damage coefficient for each unique combination of structural status, mission profile, and other operational factors; and (c) hours spent in each mission profile during the calendar quarter. Structural status refers to specific combinations of materials and finishes for several tracked locations, on the aircraft, e.g. left outer wings, etc.

The analytical problems that CTAP must solve were:

(1) Determine the functional relation between corrosion damage and the environmental factors (in the larger sense); and
(2) Calibrate the relation, i.e., determine values for the several coefficients by comparing maintenance and environmental histories _via_ multiple regression analysis.

In order to solve the second problem, several data histories would be required for each aircraft:

(a) Utilization by mission profile;
(b) airbase-possession history;
(c) structural status;
(d) IRAN/PDM data;

(e) All corrosion-related failure and corrective actions, both field and depot; and
(f) type and date of corrosion treatments/prevention.

To say the task is formidable would be a gross understatement. But with modern computers and analytical tools, it is not impossible. (Indeed, chalk-board discussion quickly expanded the list of independent variables ad absurdum (did the crew chief have a hangover?) Reason prevailed, however.)

The question of whether CTAP was feasible quickly focussed on items (e) and (f). What sort of maintenance histories exist, and are they adequate? As it turns out, there exist exquisitely-detailed maintenance records of astronomical proportions.* These records are prepared under the AFM 66-1 Maintenance Data Collection System (MDC).

The question of whether the "66-1" records are adequate is the subject of the bulk of this report. The research program described herein evolved from CTAP and addresses the possibility of using the 66-1 records to construct a corrosion-prediction program. If the records are useful, how can such a prediction model be developed? If they are not, then what changes should be made in the MDC system to make them useful for the development of such a program.

This study is not the first attempt to use maintenance-data histories in the analysis of maintenance management problems. Moore (5) sought to identify the major environmental

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*Records of the C-141A Force, over a 6-year period fill nine reels of computer tape. Records of the U.S. decennial census reportedly are contained in three reels.

factors in airborne-equipment maintenance by comparing maintenance costs with environment. In order to simplify the problem the scope of his study was restricted to two components, the KC-135 Doppler Radar and the F-4E engine starter. One is a relatively old electronic device and the other a relatively new mechanical component. These components were selected for several reasons, the most significant being that there is a high probability of failure detection and repair.

Maintenance cost data used by Moore were labor manhours selected according to Work Unit Codes from the Maintenance Data Collection System/AFM 66-1 records for the calendar year 1973. Several sources, notably HQ AFLC anlysts, attested to the reliability and accuracy of field maintenance data, but no such assurances were offered for depot-level data. Accordingly, Moore analyzed only field data. This data originated at several airbases (14 F-4 and 35 KC-135 bases). Nevertheless, it was assumed that "the proportion of maintenance cost attributed to miscellaneous sources such as bad reporting, faulty design, and other such sources is the same for all observation points." (Emphasis added.) Data reliability was taken for granted.

A multiple linear-regression analysis was used by Moore to correlate maintenance manhour costs with environmental and non-environmental factors, both in combination and separately. Environmental factors included temperature, humidity, rainfall, and similar recorded data, but did not include pollutant data since they were not available. Non-environmental factors essentially were operational events. Moore did not consider

his results conclusive because his final equation accounted for less than 80% of the variation in costs. He stated, however, that there is "sufficient evidence to conclude that environmental factors do have significant influence on maintenance costs" amounting to at least 20% of the total.

Lynch and Raymond (7) have applied multiple-linear regression analysis to develop models for predicting operational and support costs (cost-estimating relationships) from historical maintenance data. Like Moore (5), they focused their attention on a specific avionics subsystem (inertial measurement unit) for somewhat similar reasons. The maintenance data used, which were derived indirectly from the AFM 66-1 MDC system records (via Increase Reliability of Operational Systems-IROS-KO51 PN 4L), covered fiscal years 1973 and 1974.*

Data reliability was of considerable concern. In their efforts to assess it, Lynch and Raymond found opinions favoring depot-level data as being better than field-level data. They recognized that "field maintenance data validity is open to question due to (sic) the large number of different people recording the data and the wide variance of emphasis on data accuracy in different organizations." Since field maintenance data for these units amounted to only about 10% of the total, these authors felt the impact of any inaccuracies would be minimal and made no effort to remove them.

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*Fiorello and Dey (8) have raised serious questions about the value of IROS Logistic Support Cost Reports. They state that "the KO51 ranking reports appear to be reflecting between one-quarter and one-third of the total maintenance labor and material, transportation, and condemnation costs they are designed to collect."

Lynch and Raymond's purpose was to develop cost models for use at the design stage of new systems. They viewed their results as encouraging and demonstrating that modeling of future costs from historical maintenance data can be valid provided certain conditions can be met, notably assurance of data reliability and accuracy.

In yet another use of Air Force MDCS data, Farris and Smith (9) compared intermediate-level maintenance manhours expended on line-replaceable (avionics) units with the time required for initial assembly of the unit by the manufacturer. Maintenance data were extracted from an AFLC report "LOG-K261 Report" covering the time period July 1974 through December 1975. These reports provide Air Force-wide statistics and do not distinguish between data from different airbases. (Descriptive material for "RCS: LOG - MMO (AR) 7179 Work Unit Code Corrosion Summary" - Formerly LOG - K261 - is included in Appendix I for comparison.) Farris and Smith assumed their data to be valid without question. They also found no statistically valid relation between maintenance manhours and manufacturer's assembly time, and concluded that the latter data and their approach provide no "viable alternative to the use of historical data extrapolation for forecasting intermediate-level maintenance repair time."

A more ambitious (and optimistic) study was done by Smith et al. (10) of the U.S. Army Aviation Systems Command to determine, via mathematical modeling, the optimum time intervals between aircraft overhaul (depot maintenance). Several mathematical

models were constructed on the basis of an overly-simplified assumption that the rate of field maintenance is related to the number of flying hours accumulated since the most recent depot maintenance. In an effort to compare these models with actual experience, as well as to calibrate the various coefficients in the models, it was found that the maintenance data histories were woefully inadequate.* Although the Army maintenance-data-collection system could be expected to provide adequate information, it was found that regulations concerning maintenance reporting were not followed rigorously enough. Studying the maintenance data in detail, these authors found numerous omissions and errors, and concluded that the quality of reported data must improve considerably before their models can be tested. It would seem to be more prudent still if the development of models were deferred until the quality of available data has been determined.

In addition to these studies, there have been a number by the Rand Corporation (11-16) which appear to have been based upon AFM 66-1 MDC data. Most of these relate to maintenance manpower levels, inspection intervals, and levels of maintenance policies. It is not always clear from these reports whether the data were collected at shop level, from base-level records, or from some other source. In as much as the results may depend on valid maintenance data, there is

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*Smith <u>et</u> <u>al</u>. (10) include a reasonably thorough discussion of the "levels of maintenance" (cf. USAF organizational-intermediate-and depot levels) and the maintenance data collection system used by the U.S. Army. Readers familiar with the USAF systems will conclude that they are more sophisticated, less ponderous, and more reliable than those of the Army.

no basis for comment in view of the fact that the data sources and collection methods are not identified clearly. These studies have been quite limited in scope, moreover, e.g., focusing on activity at a single airbase. Consequently, at the present level of development of these studies, they should not be generalized to a great extent. The major problem with them has been identified (14)".......that analysis of Air Force maintenance may involve various unpredictable complications that would require analysts to be experienced not only in a variety of analytic techniques, but also in the policies, procedures, and operations under which the data were gathered." We agree.

This Research Program was designed along the lines of CTAP to determine the feasibility of predicting corrosion maintenance costs and, if possible, to develop a predictive model. It was intended to impact the time interval between depot maintenance. In current Air Force practice, individual aircraft are scheduled for overhaul at fixed time intervals (Programmed Depot Maintenance, PDM) such as 36 or 48 months. A number of factors are used in setting PDM intervals, the overall objective being to maximize force effectiveness. The condition of aircraft when delivered to the depot varies widely, however, ranging from minimal corrosion damage to severe. Clearly, service time since the last depot maintenance is not the most important determinant of corrosion damage; other factors, e.g., weather conditions where the aircraft has been stationed or its cummulative mission profile, are more

critical. If these factors were identified and quantified, corrosion repairs could be scheduled more effectively so as to optimize the repairability vs. cost relation as well as to improve the overall efficiency of the maintenance operation.

The program was planned as a computer analysis of the operational history and corrosion maintenance records of the C-130 and C-141A cargo-aircraft fleets. The analysis would be applied to data files of

--in-service operational data by serial number,
--repair and maintenance records,
--materials, and
--weather and other relevant information.

The objectives of the analysis were:

1. to identify and quantify those factors which are effective in predicting the corrosion damage to airframe structural components;
2. to develop improved procedures of record-keeping and storage to insure collection of the predictive factors;
3. to develop a method for scheduling depot maintenance and predicting costs better than the current PDM program.

As it has turned out, problems relating to the repair and maintenance records have demanded nearly all the effort of the program.

Research was restricted to the C-141A Force, thereby minimizing the complexity to some extent, since there is only one series of these aircraft, they are relatively few in number, and all of them were assembled over a short time interval at a single factory. The number of air-bases to which they have been assigned is small, the mission-profile list is short, and nearly all of the aircraft are flown by the Military

Airlift Command. Lastly, all PDM work is done at Robins AFB. In terms of these factors, the C-130 is a vastly more complex system.

An initial phase of the project was accomplished in-house at the Air Force Materials Laboratory (AFML) from 1 January 1975 to August 1975. During this time period the Principal Investigator was a Senior Research Associate (National Research Council) with Dr. C. T. Lynch at AFML. The remainder of the work was done at Michigan State University under contract for the Air Force Systems Command between 1 September 1975 to 30 September 1977. This Final Report presents the results of both phases.

SECTION II
THE C-141A FORCE

The C-141A Aircraft is a long-range, high-speed, high-altitude monoplane designed for use as a heavy logistic transport. It was manufactured by the Lockheed-Georgia Company beginning in 1961. The first evaluation aircraft flew late in 1963, and delivery of operational aircraft began in 1964 (18) (Table 2). A total of 284 units were delivered to the Air Force (and at least one unit to NASA), and 276 remain in the Air Force inventory. In May, 1975, the mean age of the C-141A aircraft was about 104 months, with a range from 85 to 144 months (Fig. 1).

The aircraft is built around a 10 ft. X 9 ft. X 81 ft. cargo compartment. Several (32) of the planes were modified to carry the Minuteman ICBM in a special container, and these were strengthed structurally to accommodate the 86,207-lb. weight of this load. Three C-141A's are designated NC-141A, and, together with a fourth, they are assigned to Wright-Patterson AFB, AF Systems Command, (AFSC). All four are from the original five aircraft built in 1961. Although these four aircraft are structurally identical to the remainder of the C-141's in the Military Aircraft Command (MAC), they are quite different in mission and maintenance histories, particularly with respect to corrosion. Accordingly, they have been removed from the force for the purposes of this analysis.* The overall C-141A

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* A relocation of these four aircraft occurred in 1975. Formerly, they were parked in enclosed hangars, but now they are parked in the open. We expect their future maintenance experience will be more like those of other aircraft of this type.

TABLE II

NUMBERS OF C-141A AIRCRAFT MANUFACTURED AND

Year	Number Manufactured by Serial Number	Number Accepted into Inventory
1961	5	4
1963	16	
1964	45	8
1965	84	57
1966	100	101
1967	34	111
1968		3
	284	284

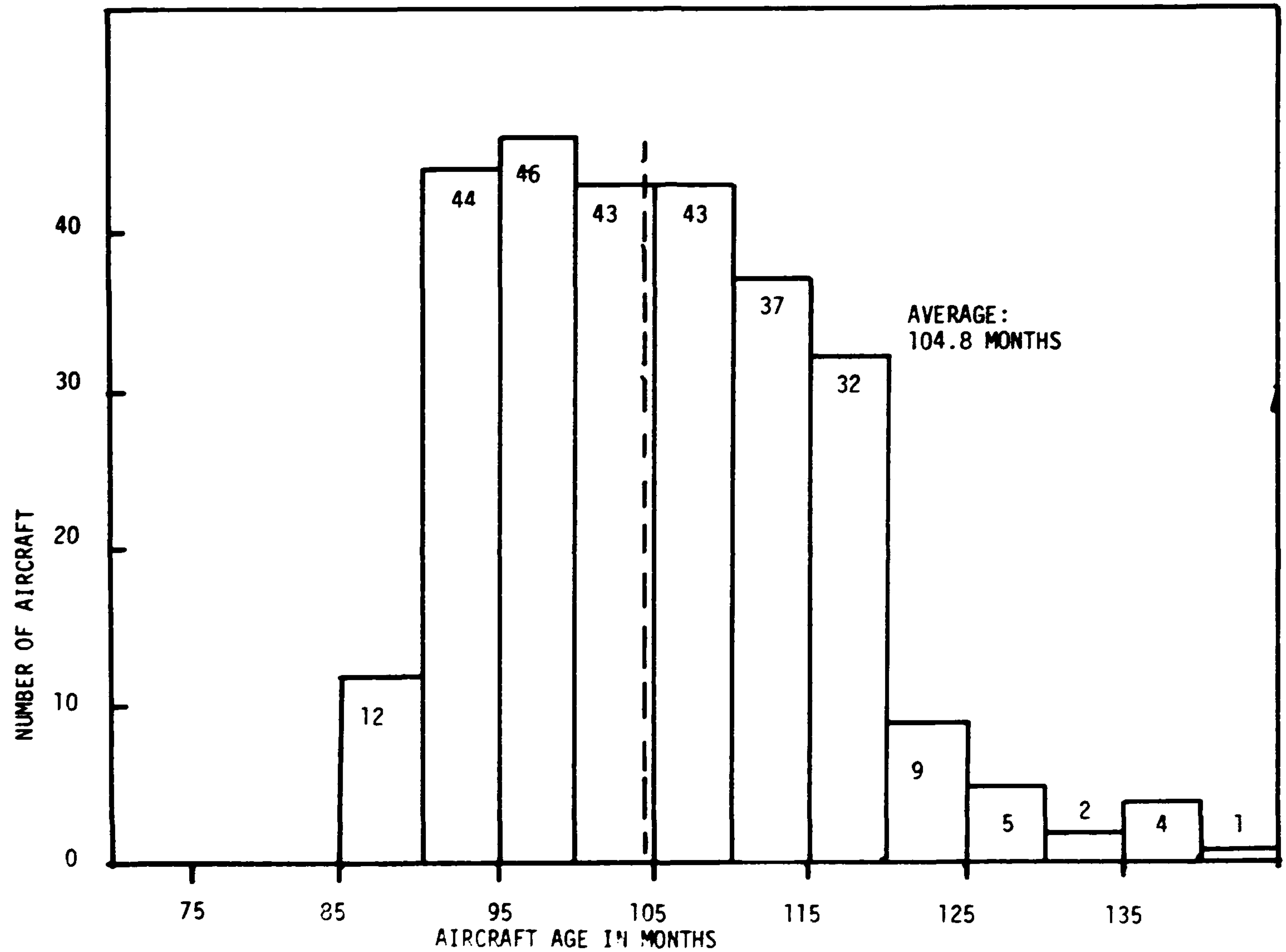

Figure 1. Calendar age distribution of C-141A aircraft as of May, 1975.

inventory by base as of January, 1976 is shown in Table 3. The airbases listed in Table 3 are:

McGuire AFB, NJ, 18 miles SE of Trenton;
Norton AFB, CA, in San Bernadino;
Travis, AFB, CA, 6 miles ENE of Fairfield and Suisun;
Charleston AFB, SC, 10 miles N of Charleston;
McChord AFB, WA, 8 miles S of Tacoma;
Altus AFB, SC, 3 miles NE of Altus;
Wright-Patterson AFB, OH, 5 miles ENE of Dayton.

In addition to these bases, some C-141A aircraft formerly were stationed at Dover AFB, DE (3 miles SE of Dover) and Robins AFB, GA (14 miles SSE of Macon).

With the exception of a training squadron at Altus AFB, the bulk of the MAC C-141A Force is oriented to airlift missions. Such applications account for 80% of aircraft flying hours; training uses 9%, and airdrop, airborne, and flight test use the remaining 11% on a force-wide bases (see Fig. 2). The bulk of airlift missions are between the above-listed bases and offshore locations, over both trans-Atlantic and trans-Pacific routes (19, 20).

The age distribution of these aircraft is shown in Figure 1, and the distribution of accumulated flight hours is shown in Figure 3, as of May, 1975 (20). The fatigue design lifetime of the C-141A is 30,000 hours. A simple comparison of the two averages in both charts shows that these aircraft are flying only 20% of the time, and spend the rest on the ground, with bulk of ground time spent at the home station. As we will discuss later, the distribution of flying hours among the several categories of mission is not uniform from one base to another, i.e., each airbase has a characteristic mission profile.

TABLE 3. C-141A INVENTORY BY BASE, JANUARY, 1976

Base		Assigned
McGuire		59
Norton		59
Travis		40
Charleston		59
McChord		39
Altus		18
WPAFB (AFSC)		4
	TOTAL	278

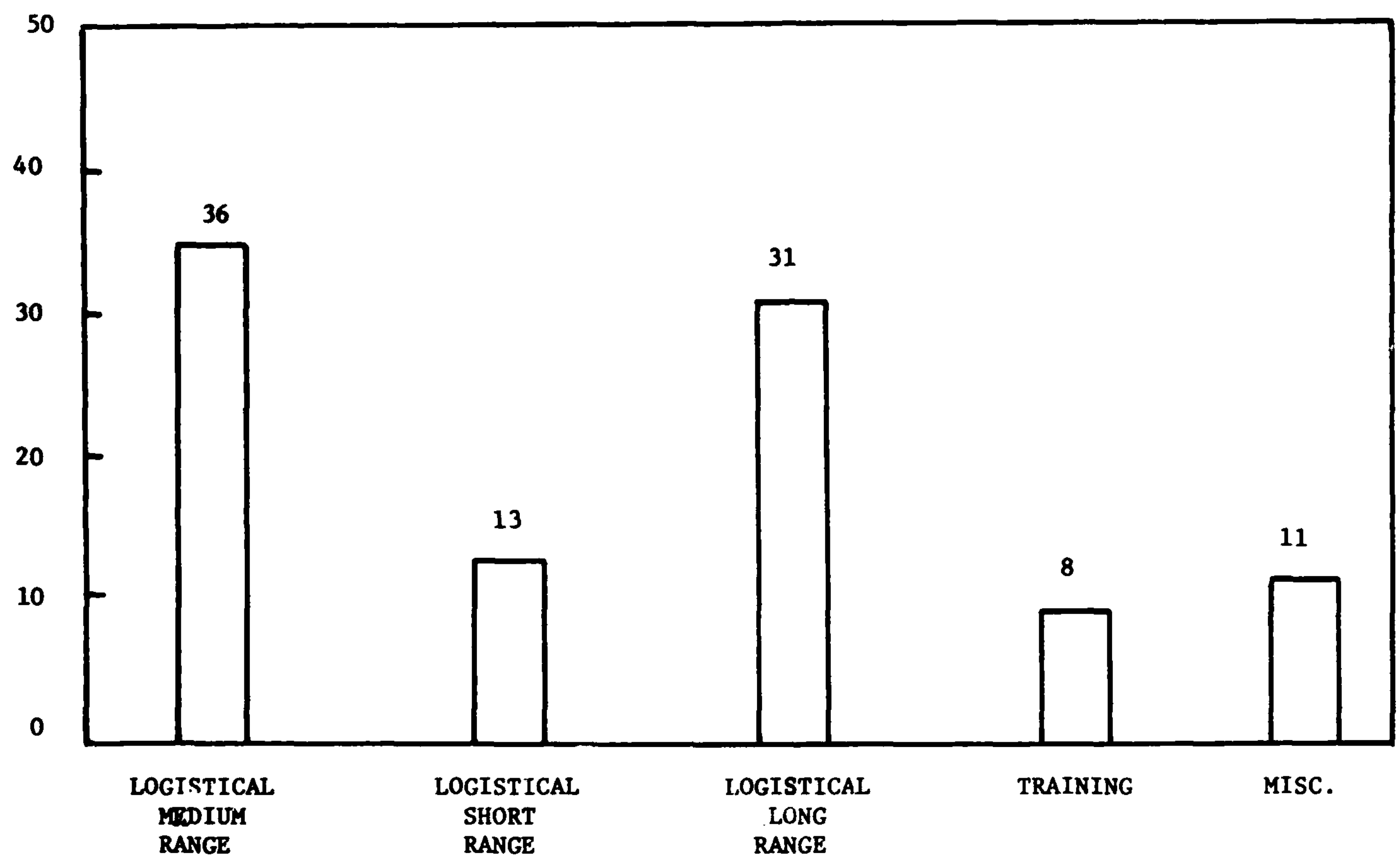

FIGURE 2. MISSION PROFILE C-141A (MILITARY AIRLIFT COMMAND), FLIGHT HOURS, MAY 1975.

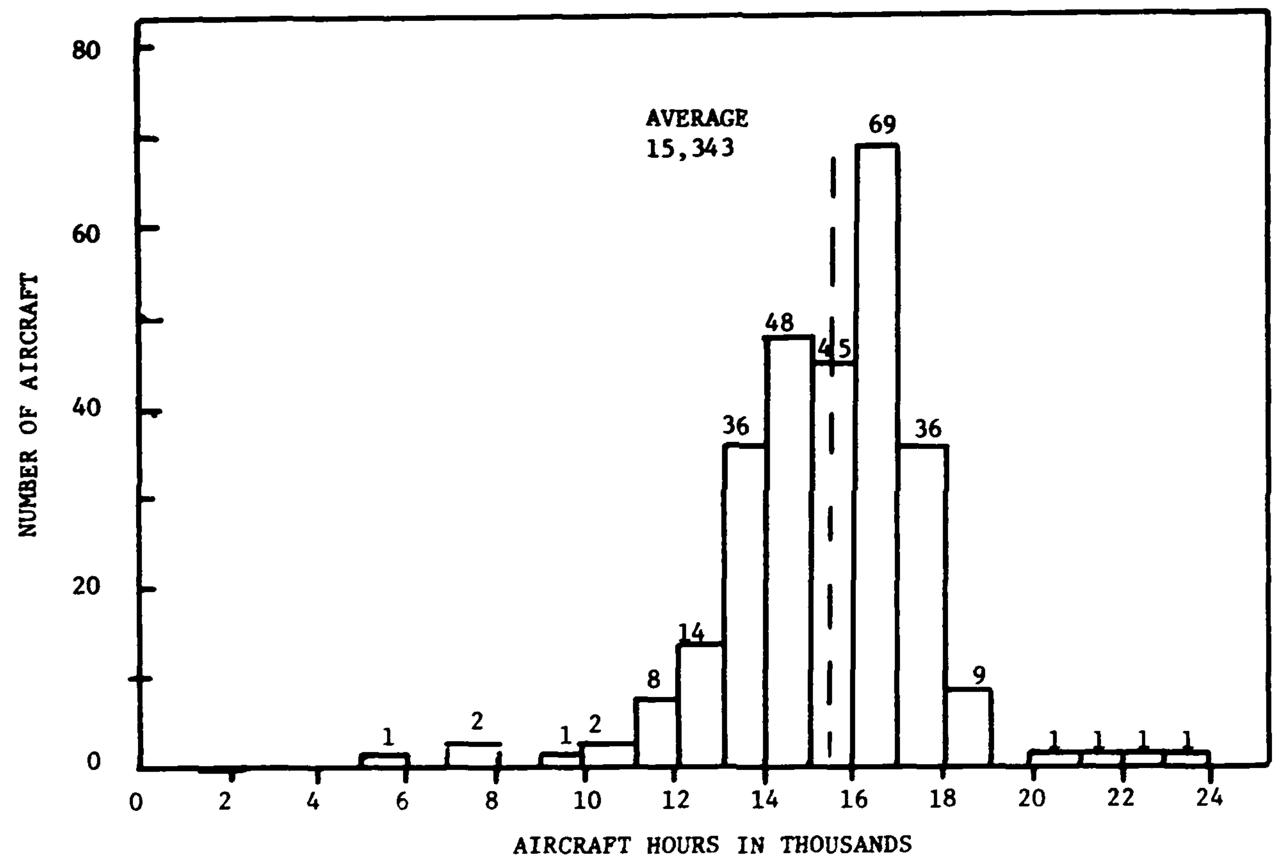

FIGURE 3. C-141 FLYING HOUR DISTRIBUTION, MAY 1975

Individual aircraft are transferred occasionally from one base to another. Within the time period of this study, two major transfers occured, which apparently were related to the dissolving of certain operational units. The major purpose for individual transfers is to spread the wear and tear of Altus training missions over the entire force. Over the time period of this study, however, approximately 250 aircraft were stationed at not more than two bases, and more than one hundred were stationed at a single base (see Table 4).

Thus, individual aircraft spend long periods of time assigned to the same base, and most of that time is on the ground. These airbases are distinctly different from one another with respect to missions flown and destinations, as well as weather, atmospheric pollutants, and many other factors relevant to corrosion maintenance. Consequently, it clearly is <u>not</u> reasonable to consider the C-141A Force environment as homogeneous (19, 20).

Table 4. Numbers of C-141A Aircraft Assigned to a Single Air Base or to Two Air Bases, January 1, 1970 - December 31, 1974

Second Base / First Base	Altus OK	Charleston SC	McChord WA	McGuire NJ	Norton CA	Travis CA
Altus, OK	1		6	7	5	2
Charleston, SC		30		11		
Dover, DE		16				
McChord, WA	4		12		4	8
McGuire, NJ	3			34		
Norton, CA	2		4		31	
Travis, CA	1		11		7	28
Robins, GA		4	3	3	1	

SECTION III.

MAINTENANCE HISTORIES

Exquisitely detailed records are prepared and filed by the Air Force for a wide range of maintenance actions. Generally, actions which correct failures or deficiencies, and actions which modify aircraft are those which are documented. Routine servicing, such as washing, cleaning, and touchup painting, is not documented in the same way or in extensive detail. The records used in this Project are those maintained on magnetic tape by the A. F. Logistics Command (AFLC). They are prepared at the time that maintenance is effected and, with some modification, eventually are deposited on tape. Our first objective is to quantify corrosion damage to individual aircraft by reconstructing the corrective maintenance actions from these records. Accordingly, it is useful to review the procedures whereby these records are obtained, as well as their content and structure in order to understand what are the limitations of this reconstruction.

A. Inspections

An aircraft-maintenance action begins with a Discrepancy Report. In the case of corrosion maintenance, the overwhelming majority of these discrepancy reports are generated during a regularly scheduled inspection. Authorized maintenance and inspection programs in effect over the time intervals of this study* are listed in Table 5 (19, 20).

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*There is an apparent difference between the field-inspection programs as described in references (19) and (20) and those in effect at the various airbases since about 1974 (see Appendix II, p. 11.) The maintenance records do not seem to reflect this difference in any way, although one is left feeling uncomfortably suspicious about reliabi' 'y of data. Inspection interval in any event, does not seem . be a timeless constant (13).

TABLE 5. AUTHORIZED C-141A MAINTENANCE AND INSPECTION PROGRAMS IN EFFECT BETWEEN 1970 and 1976.

LEVEL	INTERVAL	INSPECTION
Field	3 Days	Pre-Flight
Field	After Flight	Thru-Flight
Field	15 Days	Home Station Check
Field	70 Days	Minor
Field	140 Days	Major
Field	36 Months	Mid-Interval
Depot	36 Months	PDM

The pre-flight inspection is performed prior to flight or no later than 72 hours after the last pre-flight, and the thru-flight is performed at the conclusion of each flight. These inspections are to assure that the aircraft is mission-ready. During the home-station check, which is performed to assure that the aircraft is suitable for continued operation, minimum scheduled maintenance (e.g., lubrication) is performed. During minor inspection, all systems are inspected visually, and a minumal number of access panels, fairings, etc., are removed. At the major inspection, all systems are inspected in depth. All access panels, fairings, etc., are removed, structural members are inspected, systems are checked operationally, complete lubrication is accomplished, and identified corrosion-prone areas are inspected.

The mid-interval inspection consists of examination of the center wing structure, wing-to-fuselage attach points, empennage area, components under floor boards, and inspection of stabilizer and controls, interior fuselage structure, wiring and tubing. Also, the corrosion-inspection requirements formerly accomplished by a separate work-card deck have been integrated into this inspection (as of 1976). The mid-interval inspection, performed at field level, is scheduled at the major inspection which falls nearest to 18 months after PDM. The Controlled Interval Extension* (CIE) aircraft receive the mid-interval inspection at the midpoint also, or 24 months after PDM.

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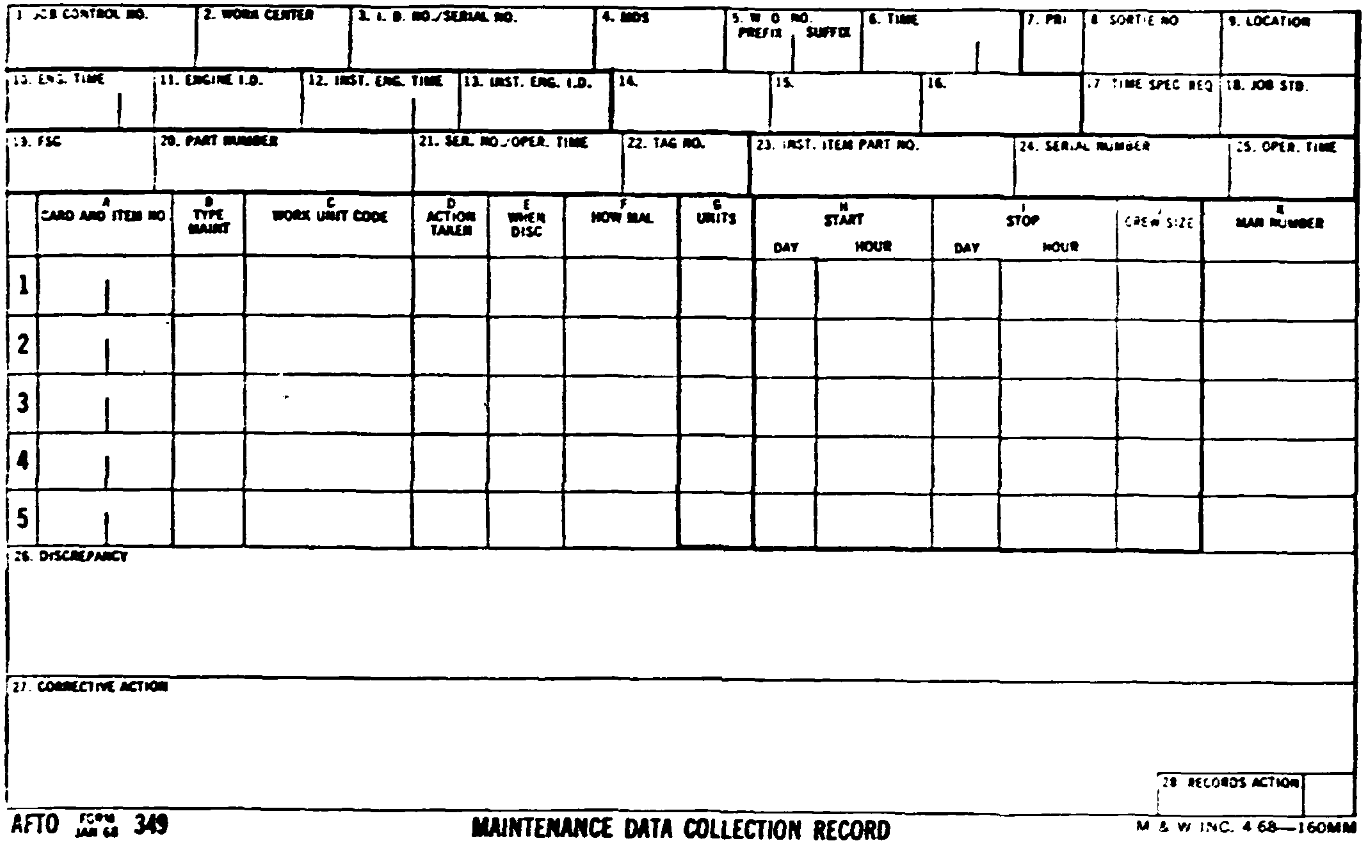
*Depot-maintenance intervals are extended-currently to 48 months-for a small number of aircraft as part of the process of determining optimum interval scheduling.

Discrepancy reports also may be initiated at inspections other then those listed in Table V. (Altogether there are 28 "When Discovered Designators" (21) which might be applicable. Interestingly, one when-discovered code is "4 - Corrosion Control Inspection," which occurs five times in our edited data file.) Such inspections, are of minor interest in corrosion maintenance, however (cf. Table II)

A discrepancy report initiates a series of maintenance events which are recorded on an AFTO form 349 (Figures 4 and 5). Periodically the AFTO 349 forms are keypunched and entered into the base computer system, and additionally, portions of some of the keypunched 349 data is forwarded to HQ AFLC. Data not forwarded are retained at base level for about 60 days, during which they are accessible *via* the Base Level Inquiry System (BLIS), and then are destroyed.

Hence, the only "permanent" maintenance records are the edited AFTO 349 data which are deposited eventually at San Antonio ALC *via* HQ AFLC (where a small amount of additional information is added.) Because of space-limitation constraints, these permanent records do not contain all of the information originally entered onto the AFTO 349. These records, as noted above, are the only available source from which the original maintenance actions can be reconstructed, except, of course, for the short-term data available locally *via* BLIS.

This set of permanent records, then, is a filtered data set. Accordingly, it is useful to examine in detail the structure of both the AFTO 349 and the permanent records to


1. JOB CONTROL NO.
2. WORK CENTER
3. I. D. NO./SERIAL NO.
4. MDS
5. W O NO. PREFIX SUFFIX
6. TIME
7. PRI
8. SORTIE NO
9. LOCATION
10. ENG. TIME
11. ENGINE I.D.
12. INST. ENG. TIME
13. INST. ENG. I.D.
14.
15.
16.
17. TIME SPEC REQ
18. JOB STD.
19. FSC
20. PART NUMBER
21. SER. NO./OPER. TIME
22. TAG NO.
23. INST. ITEM PART NO.
24. SERIAL NUMBER
25. OPER. TIME

	A CARD AND ITEM NO	B TYPE MAINT	C WORK UNIT CODE	D ACTION TAKEN	E WHEN DISC	F HOW MAL	G UNITS	H START DAY	H START HOUR	I STOP DAY	I STOP HOUR	J CREW SIZE	K MAN NUMBER
1													
2													
3													
4													
5													

26. DISCREPANCY
27. CORRECTIVE ACTION
28. RECORDS ACTION

AFTO FORM JAN 68 349 MAINTENANCE DATA COLLECTION RECORD M & W INC. 4 68—160MM

FIGURE 4. AFTO FORM 349, "MAINTENANCE DATA COLLECTION RECORD"

29. PARTS REPLACED DURING REPAIR

LINE NUMBER	A FSC	B PART NUMBER	C WORK UNIT CODE	D REF. SYMBOL	E HOW MAL	F QTY

30. CONTINUATION FROM BLOCK __________

FIGURE 5. AFTO FORM 349, "MAINTENANCE DATA COLLECTION RECORD" (REVERSE)

see what can and what cannot be inferred from the latter. First, let us summarize the steps which culminate in the creation of a permanent maintenance record.

1. An aircraft component fails or deteriorates beyond tolerance limits.
2. The failure or deterioration is noted during one of the several inspections.
3. The failure or deterioration is reported as a discrepancy, and a maintenance action (and AFTO FORM 349) is initiated.
4. The indicated maintenance action is completed and all relevant information is entered (accurately) on the AFTO 349, which then is filed with the shop supervisor.
5. Information from the 349 is keypunched and entered into the base computer system as a maintenance record.
6. Edited information from selected records is forwarded to HQ AFLC thus becoming permanent records.

It should be kept in mind that our objectives in analyzing the permanent records are to determine

(a) the rate of failure (step 1) and
(b) the consequent costs of maintenance (step 4).

The rate of failure is affected by the environmental conditions - humidity, pollutants, etc.--and these are the conditions which one might wish to modify in order to minimize maintenance costs. If the concept of "environment" is expanded to include the human factors, particularly as they impact the permanent records, then it is clear that the human environment has a greater chance to color our picture of aircraft failure and damage rates than does the "natural" environment.

B. <u>The Maintenance-Data-Collection (MDC) System</u>

This system is described thoroughly in T.O. 00-20-2 (22). Essentially, the MDCS is a set of rules concerning the maintenance information that is to be recorded on the Maintenance Data Collection Record (AFTO 349 and similar forms). The

information entered onto these forms is coded alpha-numerically. Air Force-wide codes for maintenance are contained in AF manual 300-4 Volume XI (21) and are reproduced for specific aerospace systems (such as the C-141A aircraft) in the appropriate "Work Unit Code Manual," e.g., T.O. 1C-141A-06 (23).

It is stated frequently in these documents that the information must be valid, accurate, and reliable. It is to be insured that "the data describes actually what took place and that the AFTO forms are documented according to the rules . . ." Despite the importance attached to data reliability, there is enough evidence in the permanent records to show that the level actually achieved falls considerably short of the intended mark.

There are several forms in the AFTO series, and form 349 is used to document On-Equipment (aircraft) maintenance. The information which achieves permanent-record status is that contained in blocks one through four and, from each line, block A and blocks C through J (cf. Figure 4). Blocks H, I, and J are used to compute labor manhours and are not transmitted as recorded on AFTO 349. All other data from AFTO 349 are lost, including everything from the reverse side (Figure 5).

Consequently, the permanent records do not contain part numbers, Federal Supply Classification (FSC) numbers, or other data which would relate to a specific item repaired or replaced during the course of a maintenance action. Other workers (24) have attempted to monitor maintenance costs by analyzing inventory withdrawals by FSC and similar part-

number codes. Although such studies have not been fruitful, it would be useful, nevertheless, if one could compare FSC inventory withdrawals with FSC parts replacements as recorded on AFTO 349 and related forms.

1. The Work Unit Code is the only information surviving into the permanent records which provides any clue concerning the specific component repaired, replaced, etc. The Work Unit Code* consists of five characters and identifies the system, subsystem, and component on which maintenance is effected. A few work-unit codes identify tasks of a general nature, e.g., equipment servicing, cleaning, and are called "support general codes."

As noted above, not every piece of information on a 349 form is included in the permanent records, and, moreover, certain categories of 349 forms are not included at all. The Work Unit Code decides whether a 349 form remains a temporary base-level record or becomes a permanent record. It also determines whether certain blocks on the form must be completed or if they can be left blank. Support General codes are used for recording labor costs only and usually have only base-level significance. As such labor relates to "corrosion", only two of these codes are of importance, *viz.*,

02000 Washing, cleaning, corrosion prevention treatment and decontamination; and

09000 Shop support functions, fabrication, painting, etc.

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*Much of the following material is excerpted from reference 22.

Whenever the Support General Work Unit Codes are used, there is no requirement to complete the line information items of AFTO 349, and the information is retained as a part of base-level maintenance data only. This information is not forwarded to HQ AFLC as part of the MDC system. (It is accounted for, of course, as a part of maintenance costs.)

A degree of flexibility is (and should be) allowed to field workers in deciding whether a particular maintenance action is Support General - corrosion-prevention treatment, painting, etc.- or not. Unfortunately, the use of such codes seems to be quite variable from one airbase to another (cf. Appendix II p. 10).

The first two characters of the non-Support General work-unit codes for aircraft are standard system codes which identify functional systems, e.g., flight-control systems. The third and fourth characters identify subsystems or major assemblies. The fifth character normally identifies repairable items, although there are exceptions for critical non-repairable parts.

> "All failed parts replaced during repair do not require assignment of work-unit codes because these parts are recorded in block 29 of AFTO form 349 using the federal supply classifica..on (FSC) and part number.
>
> "Work unit codes are designed as quick reference numbers to identify system, subsystem, and component relationships within end items. This provides a standard method of sorting maintenance data and of summarizing different levels of detail that is not possible through any other numbering procedure applicable to all types of equipment. Work-unit codes provide the capability to utilize data in maintenance or engineering programs by multiple systems, or components within each weapon or support system,

or by end item of equipment. This capability is also used to assess corrective actions. When combined with the equipment classification code, a highly flexible and informative data-retrieval capability is available, and is utilized at all levels of management.

"The work unit code, in combination with an action-taken code, is used to describe a "unit of work." An entry of one or more units completed must also be made in the UNITS block* of the data collection form to record a completed action. An example of a unit of work would be removal and replacement of an antenna. It would be documented with a work unit code for the antenna, with an action taken code for removed and replaced, and a unit count of one. By using additional codes to identify the end item, the type of maintenance being accomplished, when the maintenance requirement was discovered, how the item malfunctioned, and the time expended in accomplishing the work, the production credit system also provides information essential for maintenance and logistics management."

A specific aim at the initiation of this Program was to correlate corrosion damage with the materials from which the damaged items were made. Failing this, it was hoped that one could at least correlate damage with those areas on the aircraft most susceptible to corrosion, thus generating a fairly specific "hot spot" list. As it turns out, unfortunately, far too much information is lost from the original AFTO 349 form and hence neither of these objectives is realistic in terms of the AFM 66-1 data.

Although the work-unit codes number in the thousands, aircraft components are even larger in number. To illustrate, the highest-frequency work-unit code in the 1970-76 data base is 11FDA--Aft fuselage, F. S. 1058-1855, frame and/or intercostal (see Figure 6). These components seem to be as numerous as bones in an "all-you-can-eat" fish dinner, and made of

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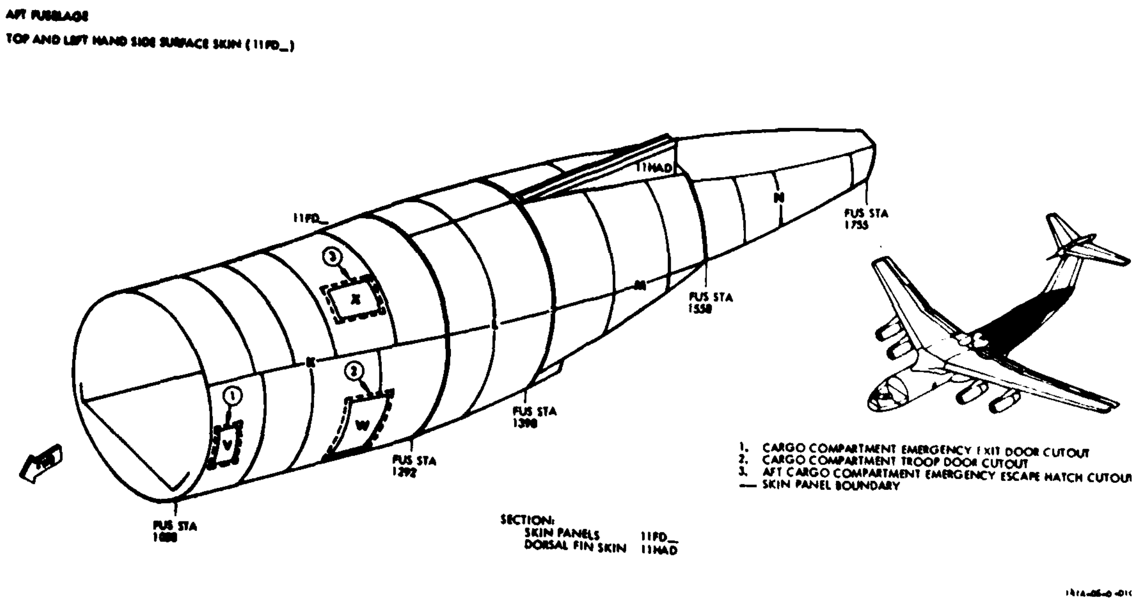
*See discussion of UNITS below.



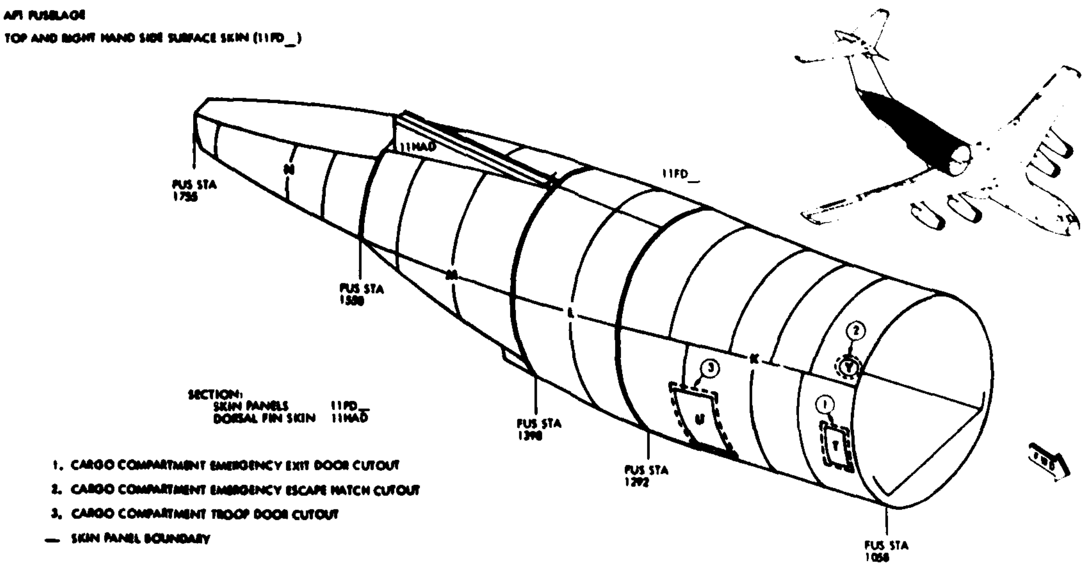


FIGURE 6. LOCATION OF WORK UNIT CODES 11 FD.

nearly as many different materials (cf. Figures 7, 8, and 9.)

Clearly the work-unit codes are not, nor were they intended to be, useful for identifying the specific component receiving maintenance. Space is provided on AFTO 349 for entry of more specific information (block 20 and the reverse side), but, as noted this information is not forwarded to HQ AFLC and is lost.

It will be shown later that one can develop a listing of "hot spots" (i.e., corrosion-prone areas) from an analysis of previous repair activity. Such areas can be described only in general terms, however, and their value suffers from another flaw: Work-unit codes are not related directly either to size or to complexity of the aircraft zone they describe. Hence a large volume of repair activity for a specific code, such as 11FDA, may result either from a larger-than-average failure rate or merely because the code refers to a large number of similar components.

2. <u>A Job Control Number</u> (JCN) is required to report each maintenance action. This is a seven-character code (reduced to 6 by HQ AFLC for permanent records) used to control and identify maintenance actions. The first three characters are the Julian day on which the JCN is assigned--in most cases this will be the same day or nearly the same day when the maintenance action is effected. The last four characters are used to identify jobs and normally consist of a daily or monthly sequence number. Essentially, JCN's are used to tie together all data, both on-equipment and off-equipment,

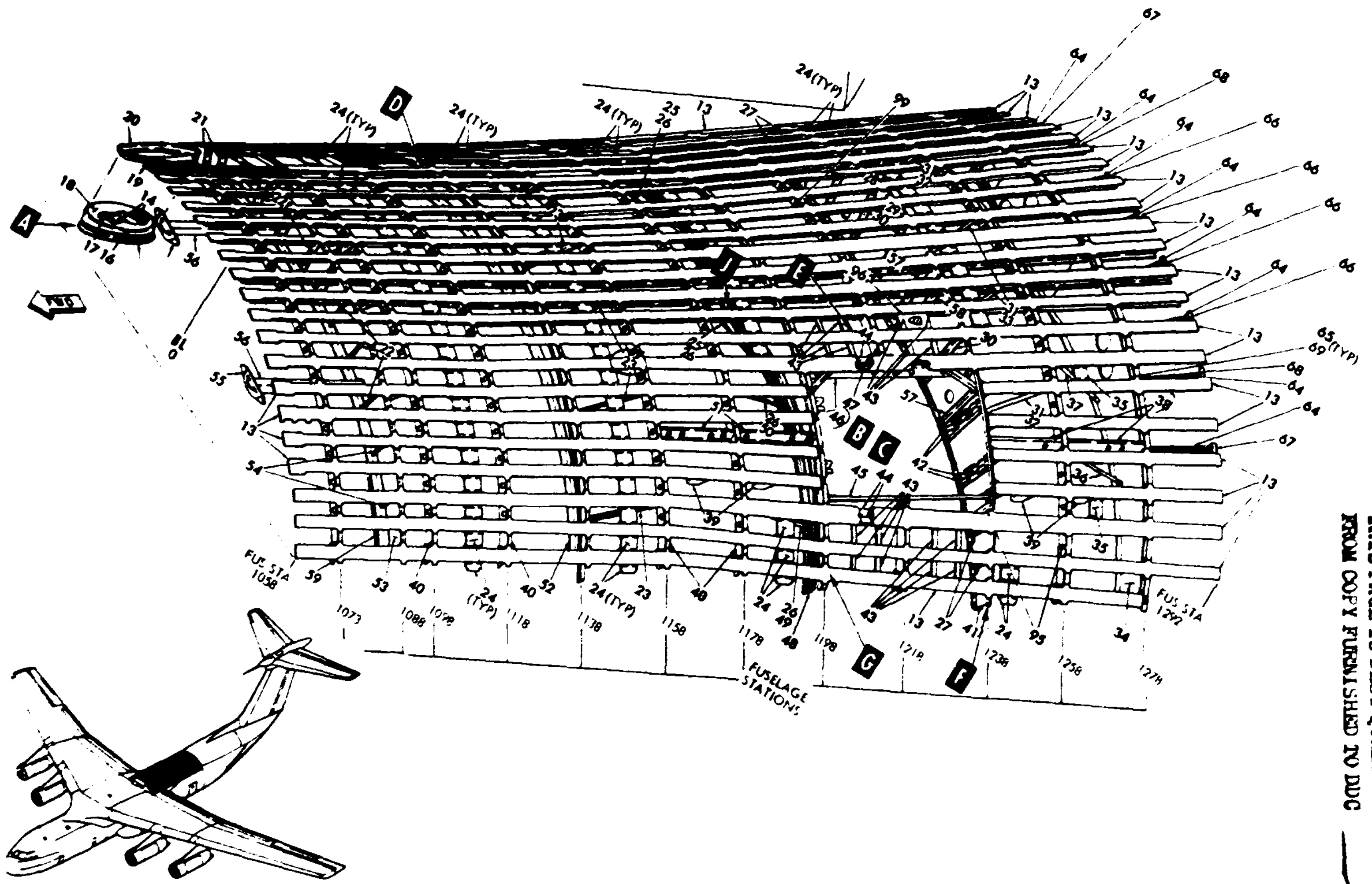


FIGURE 7. LOCATION OF WORK UNIT CODES 11 FDA, FRAME AND/OR INTERCOSTAL

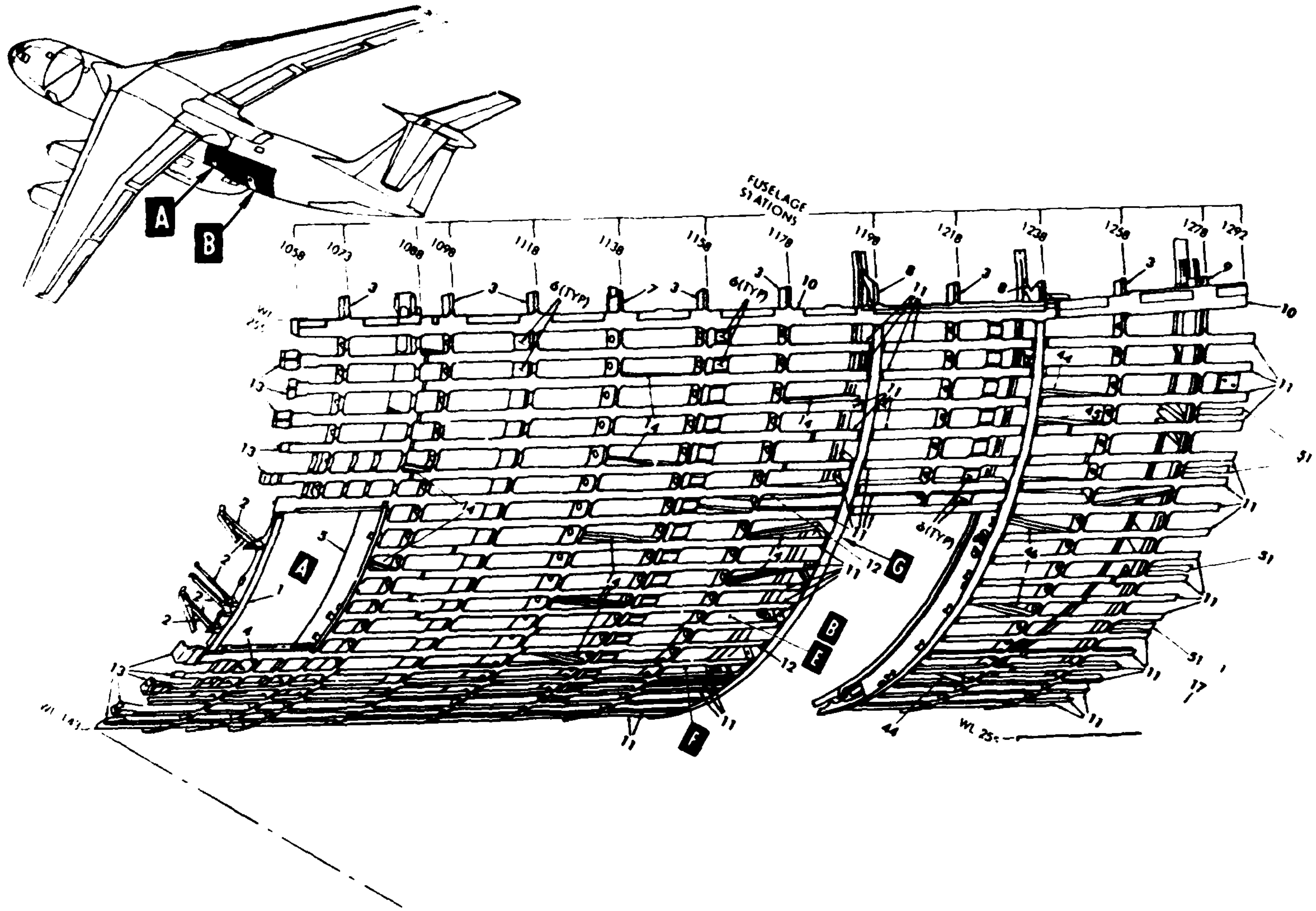


FIGURE 8. LOCATION OF WORK UNIT CODES 11 FDA, FRAME AND/OR INTERCOSTAL

INDEX NO.	DESCRIPTION	GAGE	MATERIAL	REPAIR FIGURE NO.
1	EDGING	0.063	2024-T4 CLAD	
1A	SKIN, INNER (PAN)	0.050	7075-TD	23
2	SKIN, DOOR FACING	0.032	7075-T6 CLAD	3
3	CORE, HONEYCOMB	2.0	4.5-1/8-10N (5052H-38)	3
4	FITTING, LOCK	4.0	7075-T6 BAR	
5	DOUBLER	0.040	7075-T6 CLAD	
6	FITTING, HINGE	4.0	7075-T6 BAR	
7	HINGE	1.00	7075-T6 FORGING	
8	INTERCOSTAL		LS30569-1	
9	SKIN	0.056	7075-T6 CLAD	4
10	DOUBLER	0.050	7079-T6 CLAD	
11	STRAP	0.021	6 AL-4V TITANIUM	
12	DOUBLER	0.050	7075-T6 CLAD	
13	STRINGER		LS30644-1	4-51
14	CHANNEL	0.025	2024-T4 CLAD	
15	FRAME	0.040	6061-T4	
16	FRAME	0.063	2024-T4 CLAD	
17	DIAPHRAGM	0.032	2024-T6 CLAD	
18	SKIN	0.040	2024-T42 CLAD	
19	LONGERON ASSEMBLY			
	UPPER ANGLE		LS30631-1	
	LOWER ANGLE		LS30621-1	
20	FRAME	0.080	7075-T6 CLAD	
21	STIFFENERS		LS5322	
22	STIFFENERS	0.063	7075-T6 BARE	
23	INTERCOSTAL		LS6371	
24	SPLICE PLATE	0.056	7079-T6 CLAD	
[1] 25	INTERCOSTAL	0.035	1-1/4 OD 2024-T3 TUBING	
[2] 26	STRUT		LS3253-3	
[5] 27	STIFFENER		LS6834	
[6] 27	STIFFENER		LS3961	
28	STIFFENER		LS6185	
[5] 29	STIFFENER		LS6185	
[6] 29	STIFFENER		LS3961	
[5] 30	STIFFENER		LS6183	
[6] 30	STIFFENER		LS3961	
[1] 31	INTERCOSTAL	0.035	1-5/8 OD 2024-0 TUBING	
[2] 32	INTERCOSTAL		LS3253-2	
[2] 33	INTERCOSTAL		LS6662	
34	FRAME ASSEMBLY			
	WEB	0.090	7075-T6 BARE	8-12
	CAP, UPPER ANGLE		LS30709-1	
	CAP, LOWER TEE		LS30713-1	
	STRAP, LOWER CAP	0.375	7075-T6 BARE	
35	SPLICE PLATE	0.050	7075-T6 BARE	
[1] 36	STRUT	0.035	1-1/2 OD 2024-T3 TUBING	

Aft Fuselage Forward-Top Structure and Skin Panels (Fuselage Station 1058 to 1292)

FIGURE 9. MATERIALS USED FOR 11 FDA COMPONENTS, FRAME AND/OR INTERCOSTAL.

relating to the correction of a discrepancy or modification.

Job control numbers are assigned in four basic categories: Equipment discepancies; time compliance technical orders (TCTO) and time change requirements; inspections; and support general work other than inspections. For our purposes, only the first and third categories are significant. In the case of equipment discrepancies, the JCN is important in their control, identification, and analysis. For reasons that will become apparent, however, we have made no use of the JCN.

3. The Work Center Code entered on AFTO 349 identifies the activities that performed the maintenance action being reported. Unfortunately, in the case of aircraft, this information is not forwarded to HQ AFLC. The permanent records instead contain the work center owning the equipment on which the reported action occurred, obtained from an interpretation of the aircraft serial number.

4. The Type-Maintenance Code is a single character, used to identify the type of work that was accomplished, e.g., scheduled or unscheduled maintenance. Essentially, this describes when the discrepancy was corrected.

5. The Action-Taken Code is a single character used to identify the specific maintenance action effected, e.g., removal and replacement of a component.

6. The When-Discovered Code, a single character, identifies the maintenance function or operational condition of the aircraft at the time that the deficiency or maintenance requirement was discovered.

7. <u>How-Malfunctioned Codes</u> "are designed to identify the nature of the defect and not the cause of the discrepancy." The number of such codes "is maintained at a minumum to simplify reporting." (There are more than 200 of them). We shall have more to say later about "how-mal" codes.

8. <u>Units Entries</u> permit the identification of completed maintenance actions, <u>or</u> actions that were in progress but not completed, <u>or</u> actions in which a work-center participated but was not assigned primary responsibility for completion of a maintenance action. An entry of one or more indicates the number of times that the action taken was performed. An entry of zero, however may be made for (at least) four different reasons:

(1) the work center identified in block 2 did not have primary responsibility for completing the action; or
(2) the action stopped prior to completion or was deferred more than 15 minutes; or
(3) there was a change of crew size or category of labor; or
(4) the unit was reported against a different category of labor.

Hence, although non-zero entries are reasonably unambiguous, zero entries can be a source of some uncertainty since there is no way to determine why the record was closed out.

C. <u>Permanent Data</u>

Several comments have been made in the preceding sections about changes which occur in original maintenance data before they reach the status of permanent records. The final form and contents of these records now will be discussed briefly. The record format for data in the 1970-74 period is shown in Table 6. A slightly different format was used for the later

TABLE 6. TAPE RECORD FORMAT, AFM 66-1 MAINTENANCE RECORDS.

Column	Contents		Example
1-7	Mission-Design-Series		XXC141A
8	Blank		X
9-14	Date of Record: Year, Month, Day		740804
15-22	Serial Number		65000219
23-27	Blank		XXXXX
28-32	Work Center Code		Q2000
33	Prefix	Work Order	A
34	Type Maintenance	Work Order	B
35-38	Serial Number	Work Order	021
39-40	Suffix	Work Order	95
41-45	Date of Record: Day, Month, Year (cf. cols. 9-14)		40408
46-50	Work Unit Code		11FDA
51	Action Taken		G
52	When Discovered		F
53-55	How Malfunctioned		190
56-57	Units		01
58-61	Labor Manhours (hours, tenths)		0030
62-65	Location Code		SCEY
66	Blank		X
67	Command		Q
68	Blank		X
69-71	Tag Number (usually blank)	Job Control Number	XXX
72-73	Julian day (date JCN assigned)	Job Control Number	J5
74-77	Sequence Number	Job Control Number	0417
78-79	Blank		XX
80	Card Code		Ø
81	System Manager AMA		J
82	Type Equipment		A
83	Record Identifier		J
84	Type How Malfunction		1
85-89	Blank		XXX
90	Record Mark		0-2-8

Notes:

1. Columns 1-80 are as received by HQ AFLC from Air Force bases and contractors, except the first three digits of the Job Control Number (Julian day) are compressed to two digits according to a standard formula.

2. Information in columns 80 to 89 is added by HQ AFLC.

3. Columns marked "blank" sometimes contain information, but the code is not available.

time period but the information is essentially the same. The meaning of most items has been given previously, but a few remain to be explained.

The Location is a four-character code which identifies the airbase at which maintenance was effected, and Command indicates operational authority over the equipment receiving maintenance. Card Code indicates which of several tape formats applies for this specific record. Information in columns 81-84 is added by HQ AFLC. "System Manager Air Material Area" identifies responsibility for management of the system. "Type Equipment" is used to group different equipment-classification codes into groups of similar equipment, e.g., aircraft and engines. "Record" identifies the data record and relates it to specific record layouts, e.g., "On-Equipment, Aircraft," and "Type How Malfunction" is intended to categorize how-mal codes in order to identify and separate failure information from other malfunctions and maintenance actions.

There are a number of obvious redundancies in these records, at least in those of the C-141A Force of MAC. Mission Design-Series, Command, system manager AMA, and type equipment are the same for each serial number in the force. Command does change, however, when an aircraft is transferred to Robins AFB for depot maintenance, but there also is a corresponding change in the location code. Hence the depot

command code (F) provides the same information as the Robins location code (YKHT)*.

The work center and location codes essentially are equivalent. The record date is given twice, and practically is given a third time in the job control number. The type of how-malfunction seems to be a duplication. All of these redundancies exist probably because the MDC system was devised long before the present age of extremely powerful computers.

For the purposes of reconstructing maintenance actions, the following items are of potential use:

-record date
-serial number
-type maintenance
-work-unit code
-action taken
-when discovered
-how malfunctioned
-units
-labor manhours
-location.

The job control number possibly might be of interest. With this number, one might retrieve all maintenance actions related to a record of particular interest. This does not turn out to be of practical significance, however, because large numbers of records are generated under the same JCN during certain inspections, e.g., major inspections. Although these maintenance actions are related to one another from a management

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*Depot maintenance records on the C-141A always bear the location code YKHT, which is identified (25) as Warm Springs, GA. Robins AFB codes, however, are UHJD, UHJE, UHJC (AMA), and UHHZ. No one yet has explained this discrepancy to us. If indeed there has been some foulup, we suspect it may be traceable to a graduate of our elder sister university to the east: the code for Lansing, MI is MUUU.

standpoint, they are not related as far as cause of failure is concerned. Hence, we make no use of the JCN.

The remainder of the information contained in each record is of no interest to this study.

Accordingly, it should be possible to determine from these records:

(a) what was done--action taken,
(b) when it was done--date and type maintenance
(c) why it was done--when discovered and how-malfunctioned,
(d) to what it was done--aircraft serial number, and work-unit code
(e) where--airbase,
(f) how often it was done and how much it cost to do it--units and labor manhours.

The records do not reveal who performed the maintenance.

SECTION IV.

THE C-141A CORROSION MAINTENANCE HISTORIES

The permanent maintenance histories of all USAF C-141A aircraft were provided by the San Antonio ALC on magnetic tape. Records from two time periods were covered: the fourth calendar quarter of 1970 through the fourth quarter of 1974; and the first quarter of 1975 through the fourth quarter of 1976. Data prior to 1970 were not available. These records were assumed to be complete and to represent all data which had been delivered to HQ AFLC within the respective time periods. Both organizational-level (field) and depot-level maintenance were included.

From these data-files were created two smaller files of corrosion-related maintenance. This was accomplished by removing selected records from the main files. The criterion for selection was whether the record contained one of several "corrosion" how-malfunctioned codes, or an action-taken code of "V-cleaned" or "Z-corrosion repair". The list of how-malfunctioned codes used, culled from the master list of more than 200, is given in Table 7.

There is some room for argument whether each of these codes (or others) should be thought of as being corrosion-related. None would disagree with including the two codes specifically described as "corroded". "Delamination" is generally considered an environmental-degradation problem, and so is "deteriorated". Since protective coatings and sealants are intended primarily to prevent corrosion, their loss would be a pre-corrosion condition. The codes relating to "dirty" and "cleaned" may be borderline. Out intention was to include not only obvious

TABLE 7. FREQUENCY OF HOW-MALFUNCTION CODES, C-141A FORCE-WIDE MAINTENANCE RECORDS, INCLUDING BOTH ORGANIZATIONAL- AND DEPOT-LEVEL MAINTENANCE

		4Q70-4Q74		1Q75-4Q76	
Code	How Malfunctioned	Number	Percent	Number	Percent
117	Deteriorated	10689	4.6	3350	3.8
170	Corroded, Mild to Moderate	48544	20.7	13171	15.0
190	Cracked	82806	35.4	25668	29.2
230	Dirty, Contaminated or saturated by foreign material	32538	13.9	14635	16.7
667	Corroded, severe	2090	0.9	1337	1.5
846	Delaminated	37565	16.1	17002	19.3
865	Protective coating, sealant missing	16474	7.0	10334	11.8
520	Pitted	2			
605	Crazed	0			
617	Sulfidation	0			
622	Wet, condensation	627			
910	Chipped	11			

corrosion codes but also those referring to conditions which contribute to environmental degradation, and those how-mal codes which might be used mistakenly by workers to describe true corrosion conditions.

Including how-mal "190-cracked" is more questionable to some observers. Opinions vary between two extremes: 98% of all cracked failures are pure fatigue (26) or 90% are corrosion-accelerated (corrosion fatigue or stress-corrosion cracking) (27). It is true enough that there would be no cracking in the absence of stress. It is our opinion, that cracking failure of aircraft structural components is corrosion-accelerated in most cases, hence cracking should be included in a study of the corrosion problem.

It never was intended that this project should focus exclusively on "corrosion" for at least two reasons. First, there is no agreement among corrosion scientists and engineers themselves as to what is meant by the word "corrosion." Shrier (28) offers no fewer than four definitions and spends several pages trying to explain what corrosion is and what it is not. Clearly if the experts cannot describe it, it is unrealistic to expect a maintenance technician to recognize it unerringly.

Second, we are interested in environmental damage to the aircraft in a fairly general sense. On the one hand, we have a very complex environmental history. On the other hand, we have an equally complex aircraft system whose repairs have been effected and documented by an army (sorry!) of technicians. All aspects of the problem are far too diffuse to be rigidly confined by a narrowly-defined concept.

Also listed in Table 7 are the actual numbers of records in the data which carry the selected how-mal codes. It will be noted that several of the numbers are remarkably small, which could indicate that either the problems described are quite rare, or those particular codes are rarely used. In any case, they are of so little importance in the 1970-74 data base that they were not selected-out from the 1975-76 records.

Selecting records bearing Action Taken "clean" or "corrosion repair" generated about 2700 records which do not carry one of the how-mal codes of Table 7. We refer to these as the "minor How-Malfunction codes." In some cases, these minor how-malfunction codes may be related genuinely to corrosion problems. In others, the relation between the Action ("clean" or "corrosion repair") and How-Malfunction is amusing. All of them, however, are too few in number to have any real impact in our analyses, hence there has been no further treatment of them separately. For the interested reader, they are listed in Appendix III. These cover the period 4Q70 - 4Q74; a similar listing for 1Q75 - 4Q76 has not been collected.

SECTION V.

A FORCE-WIDE OVERVIEW OF THE CORROSION MAINTENANCE HISTORY

The corrosion data base, obtained by extracting certain records from the total maintenance history, is in two parts and consists of:

1. 4Q70-4Q74: 234,046 records, 890,502 manhours; and
2. 1Q76-4Q76: 90,933 records, 273,555 manhours.

Although they are not a complete description of events in the journalist's sense (i.e., who, what, where, when, why, how, etc.) these records should provide the following information:

1. What: Specific Action Taken on an Aircraft described by its serial number, the number of action Units, and the labor Manhours.
2. Where: The airbase where maintenance was effected and work center owning the aircraft, and the Work Unit Code describing location on the specific aircraft.
3. When: the Type of Maintenance program being conducted and the date of the action.
4. Why: How Malfunctioned and operational condition of the aircraft when the discrepancy was discovered.

We cannot determine "who" since the performing-work-center-information has been lost, and "how" probably is not relevant.

We will present first a force-wide overview of the data base in order to illustrate the kinds of patterns and trends that are revealed by an analysis of this type. Later we will present aircraft-by-aircraft and base-by-base analyses which will show that force-wide studies may be seriously distorted.

In addition, there remain a few details of the MDC system which will be discussed in the force-wide overview.

Location. Nearly all corrosion maintenance actions on C-141A aircraft are effected at their own home station. Occasionally, repairs must be made while an aircraft is transient, but such repairs are a small fraction of the total and there is no reason to consider them separately. The distribution of corrosion maintenance records and manhours by percent of the total among the MAC airbases is shown in Table 8. Data normalization and comparison of the several airbases will be discussed later.

Owning work center, as discussed above, probably is of no use in this study.

Units and manhours. There are essentially two measures of corrosion damage in the maintenance history:

1. Maintenance actions, or "units of work" represented by closed-out lines on AFTO 349 forms. Frequently we refer to these as maintenance records or simply "records." Since a maintenance record is initiated by a discrepancy report, one would like to consider the records as a measure of the need for repair activity and, hence, as a measure of damage, deterioration, or failure rate.
2. Maintenance manhours, also from AFTO 349, which measures the extent of damage in terms of the cost of repair.

Table 8. Distribution of C-141A corrosion maintenance* among airbases of the Military Airlift Command, by percent.

	4Q70-4Q74		1Q75-4Q76	
Airbase	Percent Records	Percent Manhours	Percent Records	Percent Manhours
Norton	14.7	8.8	6.3	5.0
McChord	18.1	8.1	7.7	7.5
Altus	4.4	3.7	3.5	3.1
Robins	13.1	41.5	22.8	37.8
Travis	14.3	12.3	18.2	14.2
McGuire	13.3	10.2	14.8	12.0
Charleston	15.5	10.4	24.8	18.3
Dover	4.7	2.8		
Total	98.1	97.8	98.1	97.9

*Includes both organizational-level and depot-level.

As discussed above in the MDC system, non-zero entries are reasonably unambiguous and such records may be considered to be equivalent to the discrepancy reports. The same cannot be said, however, for a zero units record. Hence the extent to which zero is used can cause some uncertainties in interpreting results of data analyses. An analysis was made of the 1970-74 data base in order to determine the magnitude of this uncertainty and to estimate what distortion might result by neglecting the units column. In other words, assume that each record is a specific maintenance action or discrepancy report. The results of this analysis are shown in Table 9 as the percent of all records at each airbase which have entries of 0, 1, or 2. In addition the total percent for these three entries are listed. For four bases (Charleston, McChord, Norton, and Travis) the percent of zero entries is about the same (ca 8%). At Dover and McGuire, the values are somewhat higher and at Altus they are somewhat lower. The "sum" value shows that nearly all records at all bases carry units entries of zero, one, or two. We conclude, for the purposes of this study, that no serious distortions will result if each record in the data file is assumed to represent a specific discrepancy report and a subsequent maintenance action.

We now shall consider how the records are distributed amongst the several How Mal-Functioned codes as shown in Table 7 for the time period 4Q70-4Q74. The largest percentage of the total number of records is represented by how-mal code 190 "cracked", which accounts for over 35% of the total. The following in order of magnitude are:

Table 9. Use of "units" codes by Airbase on C-141A repair records 4Q70-4Q74 as percent of total records

Base	Units Code 00	01	02	Sum 00-02
Altus	5.5	86.4	2.3	94.2
Charleston	9.0	87.3	1.7	98.0
*Dover	12.3	84.1	1.6	98.0
McChord	8.4	88.4	2.0	98.8
McGuire	14.1	82.7	1.8	98.6
Norton	7.3	91.3	0.6	99.2
Travis	8.9	89.3	0.8	99.0
Robins	0.4	96.6	1.5	98.5

*At all bases except Dover, the number of different "units" value exceeds 25. Dover used only eight values. This may reflect a possible force-wide change in data reporting subsequent to the transfer away from Dover of C-141A aircraft.

-code 170, corroded mild to moderate, 21%
-code 846, delaminated, 16%
-code 230, dirty, contaminated etc., 14%
-code 865, protective coating etc., 7%
-code 117, deteriorated, about 5%.

Code 667, corroded severe, represents a very small part of the overall data base, less than 1% of the total records for this time period. We conclude that the difference between corroded-mild and corroded-severe, viewed by maintenance workers, is not significant, as reflected in the number of records of this type generated. In the time period 1Q75 to 4Q76, essentially the same distribution is found among these how-malfunctioned codes. The largest is cracked, 29% then delaminated, 19%, dirty 17%, corroded mild, 15% and protective coating, 12%. The relative importance is essentially the same for the most significant and least significant how-malfunctioned codes in both time periods: Cracked is the most frequent how-malfunctioned code and corroded severe is least frequent. Deteriorated occupies the same position in importance as does protective coating. There have been some changes in the relative importance of corroded mild-to-moderate, code 170, which slipped from second place to fourth place in importance, code 230, dirty, contaminated or saturated, has climbed from fourth place to third place, and code 846, delaminated has risen from third to second place. One might draw conclusions with respect to these time periods about the relative magnitude of the problems that the Air Force is experiencing with these How-Malfunctioned codes. For example, mild-to moderate corrosion problems appear to have diminished in importance between 1970-74 and 1975-76, since the relative percent of the overall data base has declined from 21% to 15%

Likewise, cracked problems, code 190, apparently also have decreased in importance, from 35% to 29%. One should be cautious however, because, there are serious distortions in force-wide data.

One obvious distortion is the difference in the importance of records as opposed to the importance of cost, represented by the manhours. The distribution of manhours among the How-Malfunctioned codes on a force-wide basis is shown in Table 10. The ordering of the percent of manhours shows some difference from Table 7. Cracked still ranks first (34% for 4Q70 to 4Q74, and 36% for 1Q75 to 4Q76). Also, corroded-severe ranks lowest in both Tables 7 and 10. In terms of manhours, however, corroded, mild-to-moderate, ranks 4th, compared with the second place in percent records (70-74). Similarly, code 170, corroded mild-to-moderate decreased from 21% to 15% of records but increased in manhours from 13% to nearly 15%.

We turn now to an examination of the distribution of records and manhours among the several when-discovered codes, i.e., operational condition of the aircraft at the time the discrepancy was discovered. In Table 11 the distribution of records is shown and in Table 12, are the manhours. In Table 11 for the first time period, the when-discovered code frequency is approximately the same for both major inspection and minor inspection. The next highest percentage is when-discovered code S, depot level maintenance, and the next lowest is F, between flights--ground crew. The percent of records discovered at major inspection is essentially the same for 1970-74 and 1975-76.

TABLE 10. DISTRIBUTION OF MANHOURS AMONG HOW MALFUNCTION CODES, C-141A FORCE-WIDE MAINTENANCE RECORDS, INCLUDING BOTH ORGANIZATIONAL-AND DEPOT-LEVEL MAINTENANCE

Code	How Malfunction	4Q70-4Q74 Percent	1Q75-4Q76 Percent
117	Deteriorated	7.1	3.7
170	Corroded, mild to moderate	12.7	14.5
190	Cracked	34.1	36.3
230	Dirty, Contaminated or saturated by foreign material	8.7	10.5
667	Corroded, sever	2.5	3.8
846	Delaminated	15.1	20.2
865	Protective coating, sealant missing	17.9	7.7

TABLE 11. DISTRIBUTION OF C-141A FORCE-WIDE CORROSION MAINTENANCE RECORDS AMONG WHEN DISCOVERED CODES, INCLUDING BOTH ORGANIZATIONAL-AND DEPOT-LEVEL MAINTENANCE

Code	When Discovered	4Q70-4Q74 Percent	1Q75-4Q76 Percent
M	Major Inspection	31.9	29.9
K	Minor Inspection	28.4	12.9
F	Between Flights-Ground Crew	12.6	18.1
S	Depot Level Maintenance	22.1	30.2
J	Preflight Inspection	1.4	2.2
Q	Special Inspection	0.7	1.9
D	In Flight No Abort.	1.1	2.1

There is a dramatic difference, however, between the respective percentages of when-discovered at minor inspection, falling from 28% to only 13%. At the same time, when discovered at depot level maintenance jumped by 8% and between flights-ground crew when-discovered also increased by 6%. Tables 11 and 12 include both organizational-level (field) as well as depot-level maintenance, hence, the relative importance of depot-level maintenance probably is overemphasized.

Table 12, the distribution of manhours among the when-discovered codes, shows how including depot-level maintenance can grossly distort the picture. In the first time period, depot-level maintenance accounts for nearly 50% of the total manhours, compared with only 22% of the discrepancies discovered (records, Table 11) in the same time period. Table 12 also illustrates the decline of manhours at minor inspection, from 12% to only 5%. On the other hand there is an increase from 19% to 26% of the total records for when-discovered-between flights, ground crew. It is clear then that force-wide analyses must be made on data which have been separated with respect to organizational-level (field) maintenance and depot-level maintenance.

The frequency of action-taken codes, force-wide, is listed in Table 13. The most important action taken code is G, repair and/or replacement of minor parts etc., 42% in the first time period, and nearly 50% in the second time period. Of lesser importance are code Z, Corrosion Repair, and V, Clean, which in the first period are about 20% and 13%, and, in the

TABLE 12. DISTRIBUTION OF MANHOURS AMONG WHEN DISCOVERED CODES, C-141A FORCE-WIDE MAINTENANCE RECORDS, INCLUDING BOTH ORGANIZATIONAL-AND DEPOT-LEVEL MAINTENANCE

Code	When Discovered	4Q70-4Q74 Percent	1Q75-4Q76 Percent
M	Major Inspection	14.3	14.9
K	Minor Inspection	11.7	5.0
F	Between Flights-Ground Crew	19.4	26.0
S	Depot Level Maintenance	47.9	42.7
J	Preflight Inspection	2.8	3.7
Q	Special Inspection	0.7	3.0
D	In-Flight No Abort	1.3	2.0

TABLE 13. FREQUENCY OF ACTION TAKEN CODES, C-141A, FORCE-WIDE, MAINTENANCE RECORDS, INCLUDING BOTH ORGANIZATIONAL- AND DEPOT-LEVEL MAINTENANCE.

		4Q70-4Q74		1Q75-4Q76	
Code	Action Taken	Number	Percent	Number	Percent
G	Repairs and/or Replacement of minor Parts, etc.)	98983	42.3	43633	49.6
Z*	Corrosion (Repair)	46306	19.8	12686	14.4
V*	Clean	30422	13.0	15762	17.9
F	Repair	21628	9.2	1814	2.1
R	Remove and Replace	21577	9.2	8211	9.3
P	Removed	9550		3657	
Q	Installed	2402		637	
X	Test-Inspection-Service	1339		441	
Y	Troubleshoot	1478		885	
L	Adjust	253		88	
K	Calibrated-Adjustment Required	64		12	
E	For Future Use	22		65	

* Z and V were selected, hence the numbers for these two codes represent the totals in the entire data base.

second period, 14% and 18% respectively, the relative order of their importance being reversed. The two codes F, Repair, and R, Remove and Replace, in the first time period amount to about 9%, whereas in the second time period, code R remains at 9% but F declines to only 2%. The definitions of the action-taken codes are a source of considerable ambiguity and uncertainty as to precisely where and when they are to be applied. This question is reviewed in the discussion section of this report as well as in a separately published appendix by the Principal Investigator and the Project Engineer.

It is amusing that Action-Taken code P, Removed, is approximately four times larger than Action-Taken code Q, Installed, for the first period, and nearly six times larger in the second period. There is, of course, some simple explanation for this difference, but a passenger on a C-141A, must reflect on those components removed but not replaced. Perhaps more time is needed to install components than to remove them. Unfortunately Table 14 shows that the manhours spent on code P also exceed the manhours used to install parts.

The distribution of manhours and records among the work unit codes is shown in Table 15. Choosing an arbitrary value of 5% or greater as a significant value, we see that in the first period work unit codes 11 FA, forward fuselage nose to FS 451, 11FE, forward fuselage FS 451 to 735, and 14GA wing-flap assembly, appear to be particularly severe problems with respect to manhours. Code 46AA, fuel tank general also stands out prominently. If one considers instead the percentage of

TABLE 14. DISTRIBUTION OF MANHOURS AMONG ACTION TAKEN CODES, C-141A FORCE-WIDE MAINTENANCE RECORDS, INCLUDING BOTH ORGANIZATIONAL- AND DEPOT-LEVEL MAINTENANCE.

Code	Action Taken	4Q70-4Q74 Percent	1Q75-4Q76 Percent
G	Repairs and/or Replacement of minor parts, etc.	45.2	41.4
Z*	Corrosion (Repair)	11.0	14.3
V*	Clean	8.9	12.8
F	Repair	8.5	3.8
R	Remove and Replace	17.7	18.1
P	Removed	5.7	5.4
Q	Installed	2.0	2.4
X	Test-Inspection-Service	0.3	1.0

TABLE 15. DISTRIBUTION OF C-141A FORCE-WIDE CORROSION MAINTENANCE AMONG SELECTED (MAJOR) WORK UNIT CODES, INCLUDING BOTH ORGANIZATIONAL- AND DEPOT-LEVEL MAINTENANCE.

Work Unit Code	4Q70-4Q74 Percent Manhours	4Q70-4Q74 Percent Records	1Q75-4Q76 Percent Manhours	1Q75-4Q76 Percent Records
11BA Cargo Ramp, General	3.2	4.6	2.5	3.1
11BD Petal Doors, General	2.9	4.0	2.7	3.1
11BK Pressure Door, General	0.9	1.0	1.3	1.1
11EA Main Landing Gear, Outboard Door	2.0	2.3	2.4	2.3
11EB Mail Landing Gear, Inboard Door	0.7	0.7	0.8	0.8
11EE Aft Nose Landing Gear Door	1.7	2.0	1.5	2.1
11FA Forward Fuselage, Nose to F.S. 451	7.1	6.6	5.1	5.1
11FB Forward Fuselage, F.S. 451-735	6.5	4.8	6.4	4.7
11FC Center Fuselage, F.S. 735-1058	3.0	2.8	2.5	2.4
11FD Aft Fuselage, F.S. 1058-1855	4.9	6.3	5.1	5.2
11FE Wheel Well Pod	4.7	5.2	4.1	4.5
11GA Center Wing-Box Beam	2.3	2.5	6.9	4.1
11GB Inboard Wing	3.0	3.4	7.3	6.8
11GC Outboard Wing	3.0	3.4	6.9	5.8
11GE Pylons	4.0	3.7	4.7	3.9
14AA Aileron Control System	1.4	1.9	1.1	1.4
14GA Wing Flap Assembly	5.1	6.6	4.0	4.8
14GB Wing Flap-Mechanical	0.9	1.4	0.3	0.6
14HD Wing Spoiler-Mechanical	1.0	1.3	1.1	1.4
46AA Fuel Tank-General	21.5	5.9	8.8	11.2

records, the importance of these particular work-unit codes does not change significantly with the exception of 46AA fuel tank which is only 6% of the records. The large difference of apparent fuel-tank problems between manhours and records is the result of including in Table 15 both depot maintenance and field-level maintenance. The apparent magnitude of fuel-tank problems declined dramtically, however, from the first time period to the second time period, from 22% to only 9% of man-hours.

In addition to the distortions introduced by performing analyses on a data base which included records from both depot and field levels, there also are base-to-base variations which skew the results. Consequently, no further analyses were made of the data in this form.

SECTION VI.

CUMULATIVE MAINTENANCE HISTORIES OF INDIVIDUAL AIRCRAFT

The cumulative chronological maintenance histories, both as repair records and repair manhours, were plotted for all aircraft for 4Q70-4Q74. An example of these plots is shown in Figure 10. Several maintenance events are apparent in these charts. All of them show a step-like function corresponding to the major field inspection at approximately 70-day intervals. The 15-day home-station inspections also are frequently apparent as smaller steps. In many of the charts, although not all, the programed depot maintenance appears as a large increase. Presumably major inspections at 140-day intervals should appear larger on the charts, and in some cases this is observable. Also one might expect to find 360-day mid-interval inspection, but they are not always visible. The curves for both maintenance records and maintenance manhours are nearly linear with time. A straight line may be drawn through the maintenance histories and its slope measured which represents the rate of field maintenance actions or field maintenance manhours. After examining a number of these charts and comparing them with base assignment, it is clear that the rate of field maintenance is virtually a fingerprint not only of each aircraft but also of the airbase. The charts of no two aircraft are identical, of course, but the charts for aircraft stationed at the same airbase are sufficiently alike that they easily are sorted according to airbase, based only on the field maintenance slope. Some airbases are similar, however. For example, it is difficult to distinguish the charts of aircraft from Charleston AFB

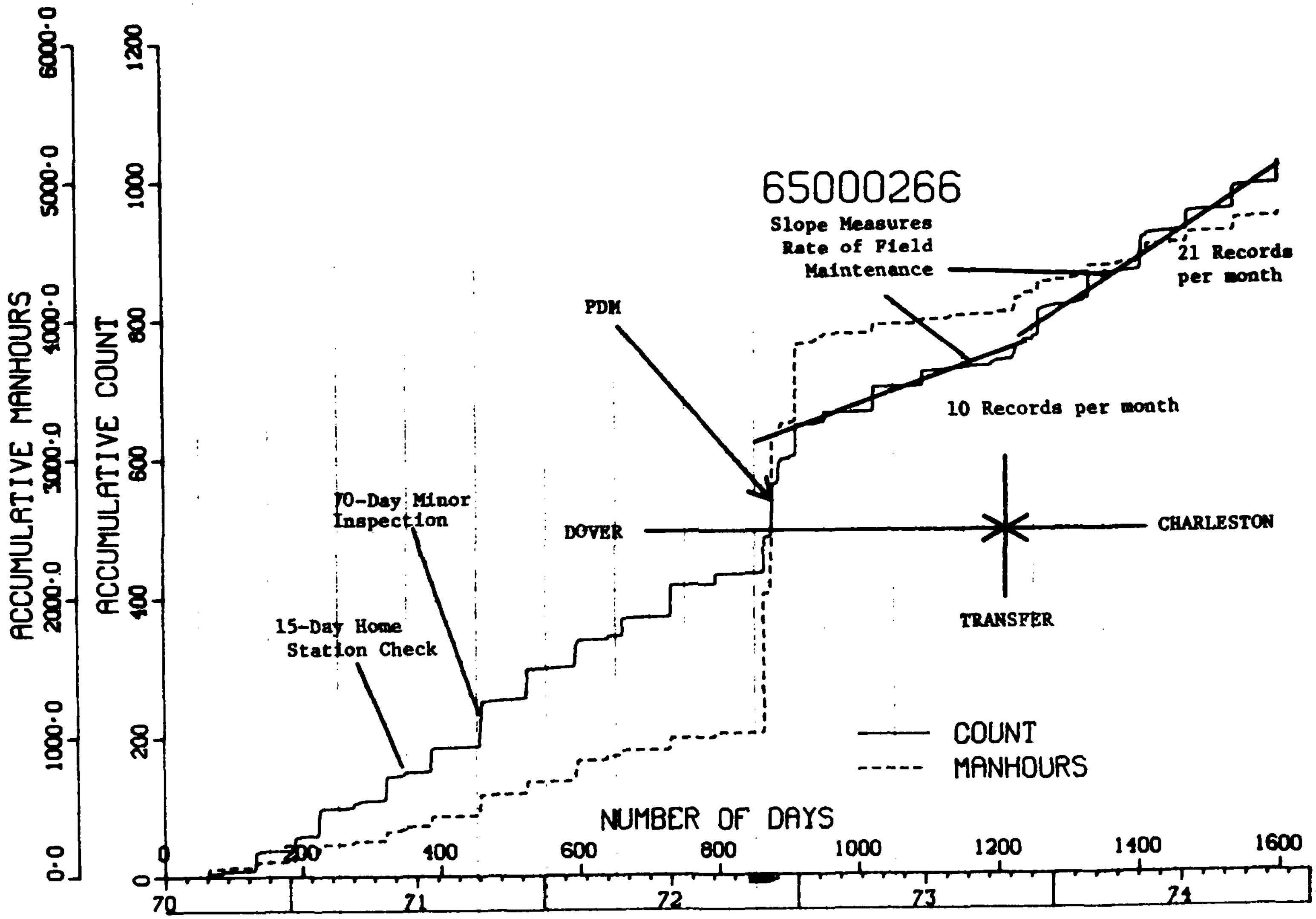

FIGURE 10. C-141A SN 650266, ILLUSTRATING SEVERAL FEATURES OF CORROSION REPAIR HISTORY. THIS AIRCRAFT WAS TRANSFERRED FROM DOVER AFB TO CHARLESTON AFB, 4Q 1973.

from those of aircraft which were stationed at Norton AFB. The charts of aircraft stationed at Altus AFB and McGuire AFB also are similar. The differences between records from McChord, Travis, and McGuire AFB's, however, are striking and one would never fail to distinguish these bases from one another. Representative charts of aircraft which have been assigned continuously to the various airbases are shown in Figures 11-16. An inset chart shows the period 1975 through 1976, plotted to the same scale. In every case the graphs are more or less linear over both time periods and the slope of the curves does not change significantly. Charts from Travis AFB, Norton AFB, and Charleston AFB, Figures 13, 15, and 16, respectively, show relatively high rates of field maintenance. On the other hand, the charts of McGuire, AFB, Figure 12, and Altus AFB, Figure 11, exhibit a smaller rate of field maintenance. Field maintenance at McChord AFB, Figure 14, is strikingly different from that at the other bases showing a high rate of field maintenance between 1970 and the third quarter of 1972, but a substantially lower rate thereafter. This pattern is visible in the record of every aircraft stationed at McChord AFB and is one of the most striking features of the charts. No explanation has been found for this downward convex curve, hence we refer to this as the "McChord Anomaly."

There also is an anomaly for aircraft stationed at Norton AFB, Figure 16, which consists of gaps in the data, i.e., time periods in which no records or maintenance manhours appear in the permanent data base. The Norton Anomaly is visible as a flat

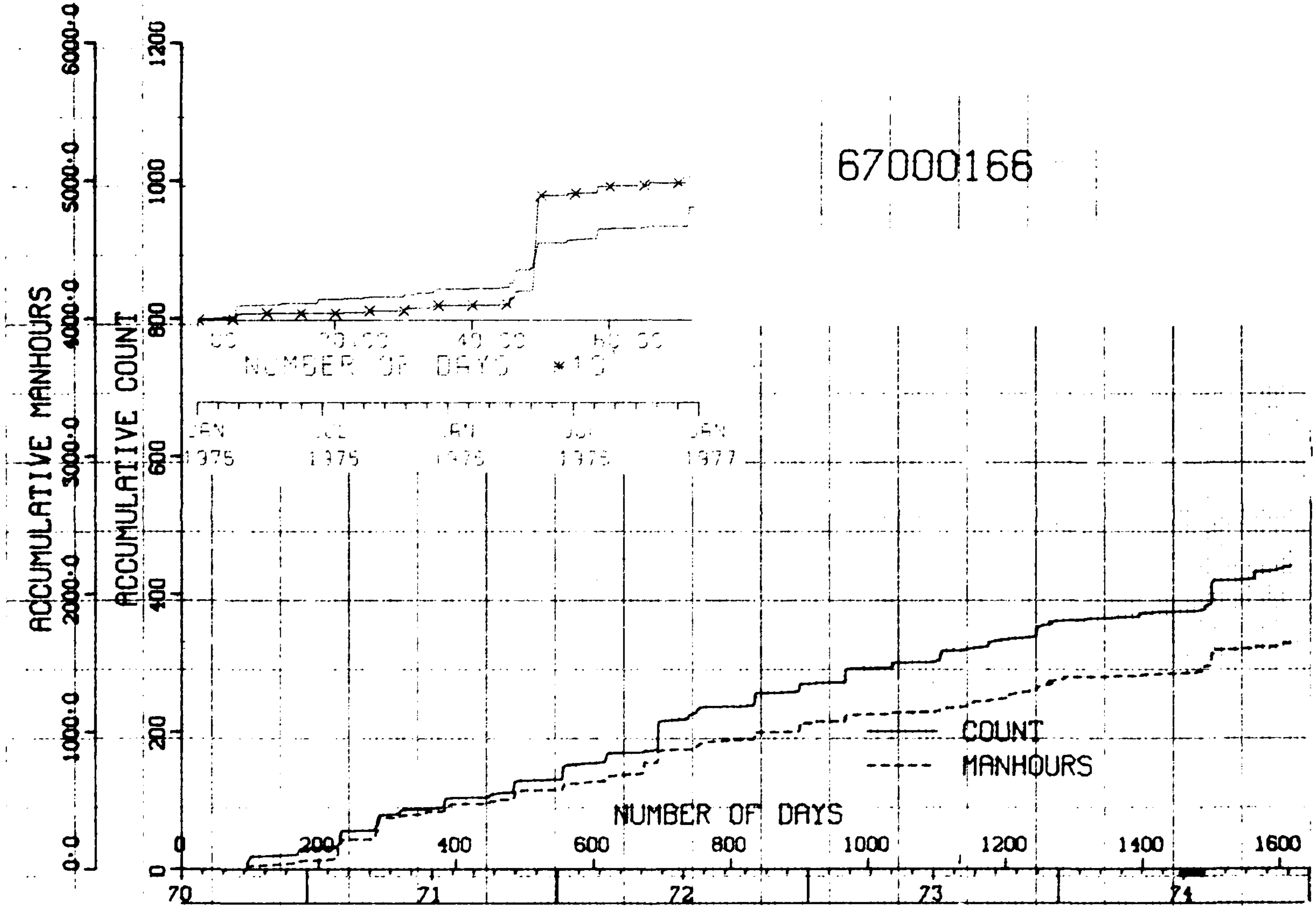

FIGURE 11. C-141A SN 67000166, ASSIGNED CONTINUOUSLY TO ALTUS AFB.

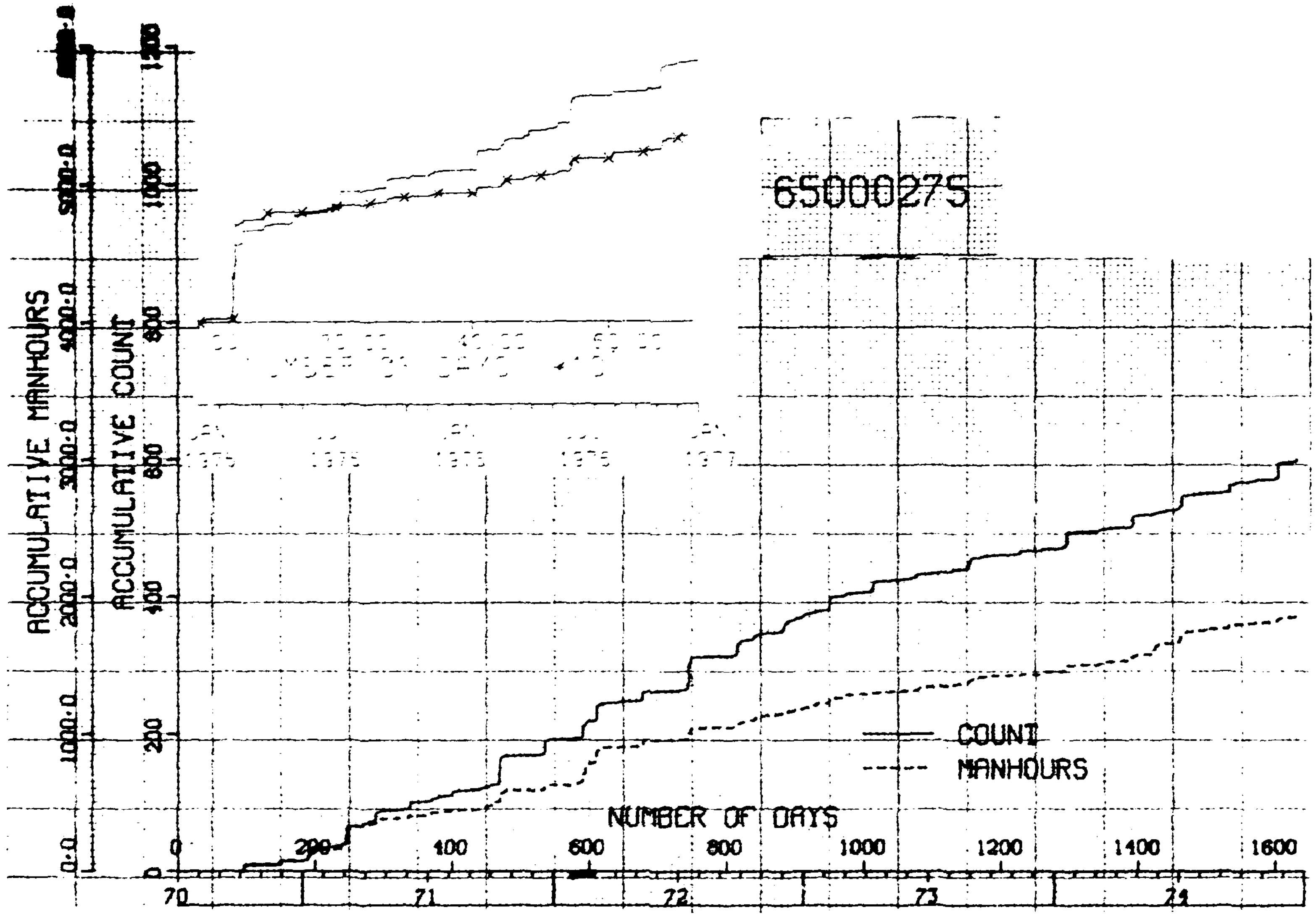

FIGURE 12. C-141A SN 65000275, ASSIGNED CONTINUOUSLY TO McGUIRE AFB.

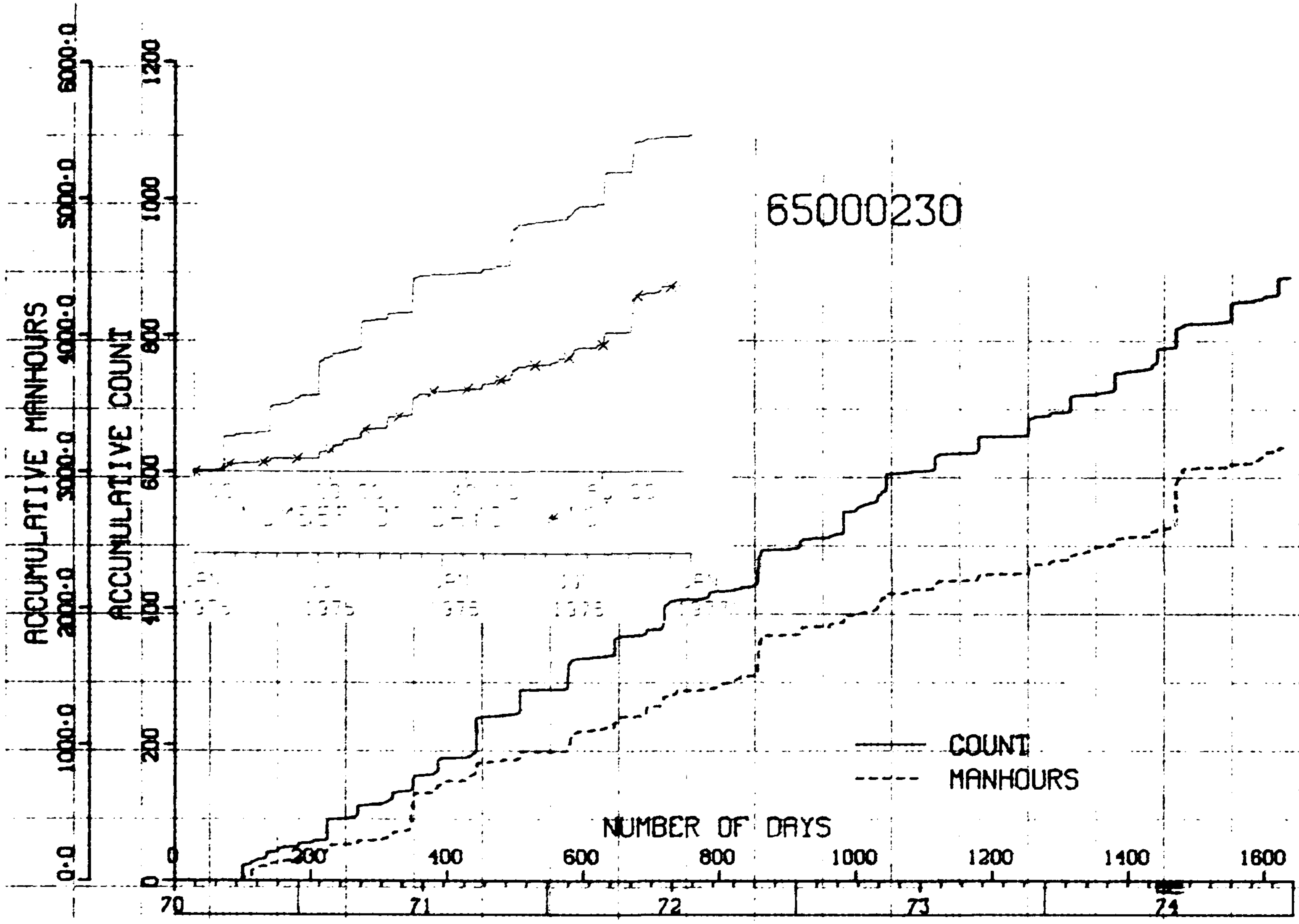

FIGURE 13. C-141A SN 65000230, ASSIGNED CONTINUOUSLY TO TRAVIS AFB.

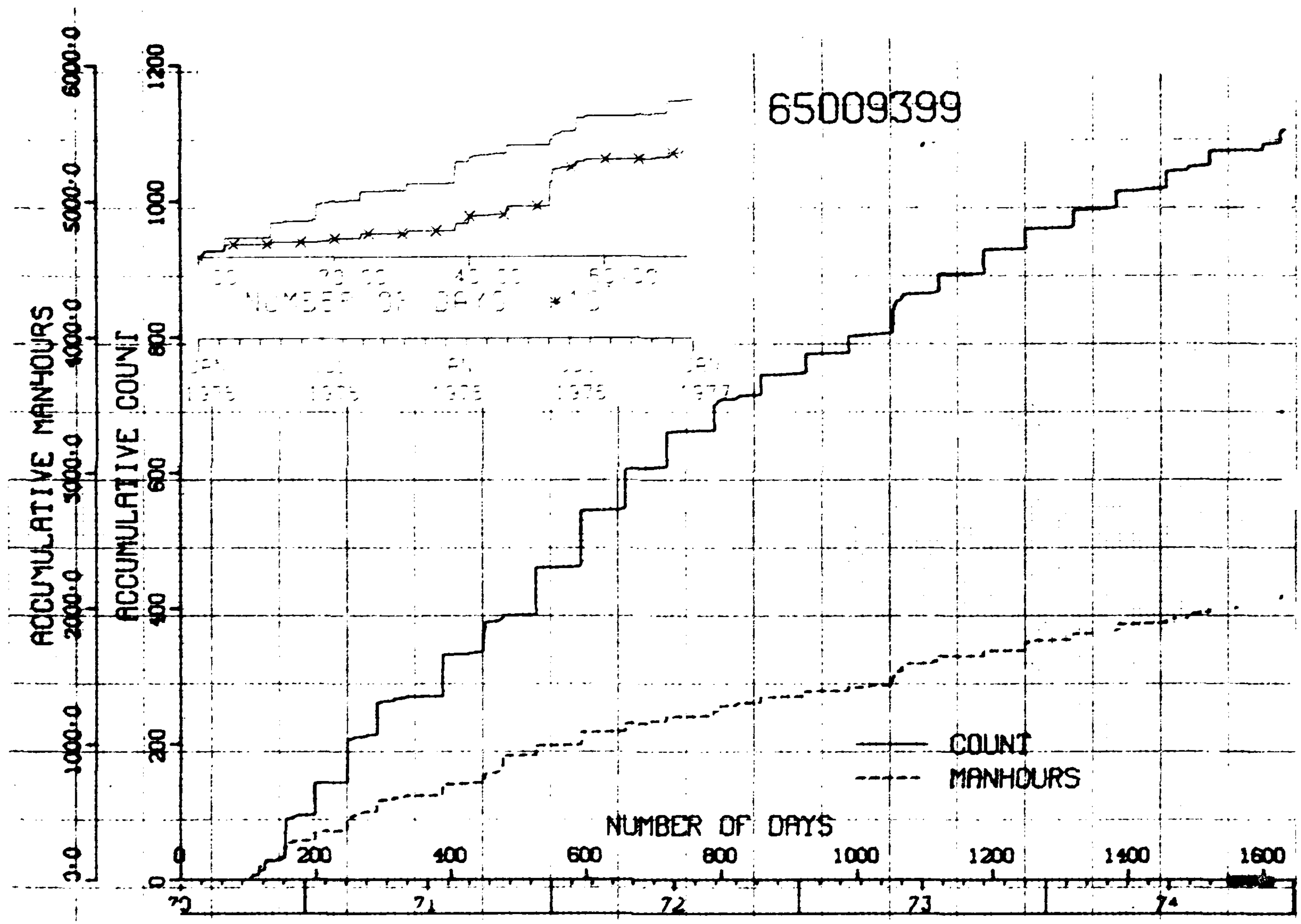

FIGURE 14. C-141A SN 65009399, ASSIGNED CONTINUOUSLY TO McCHORD AFB.

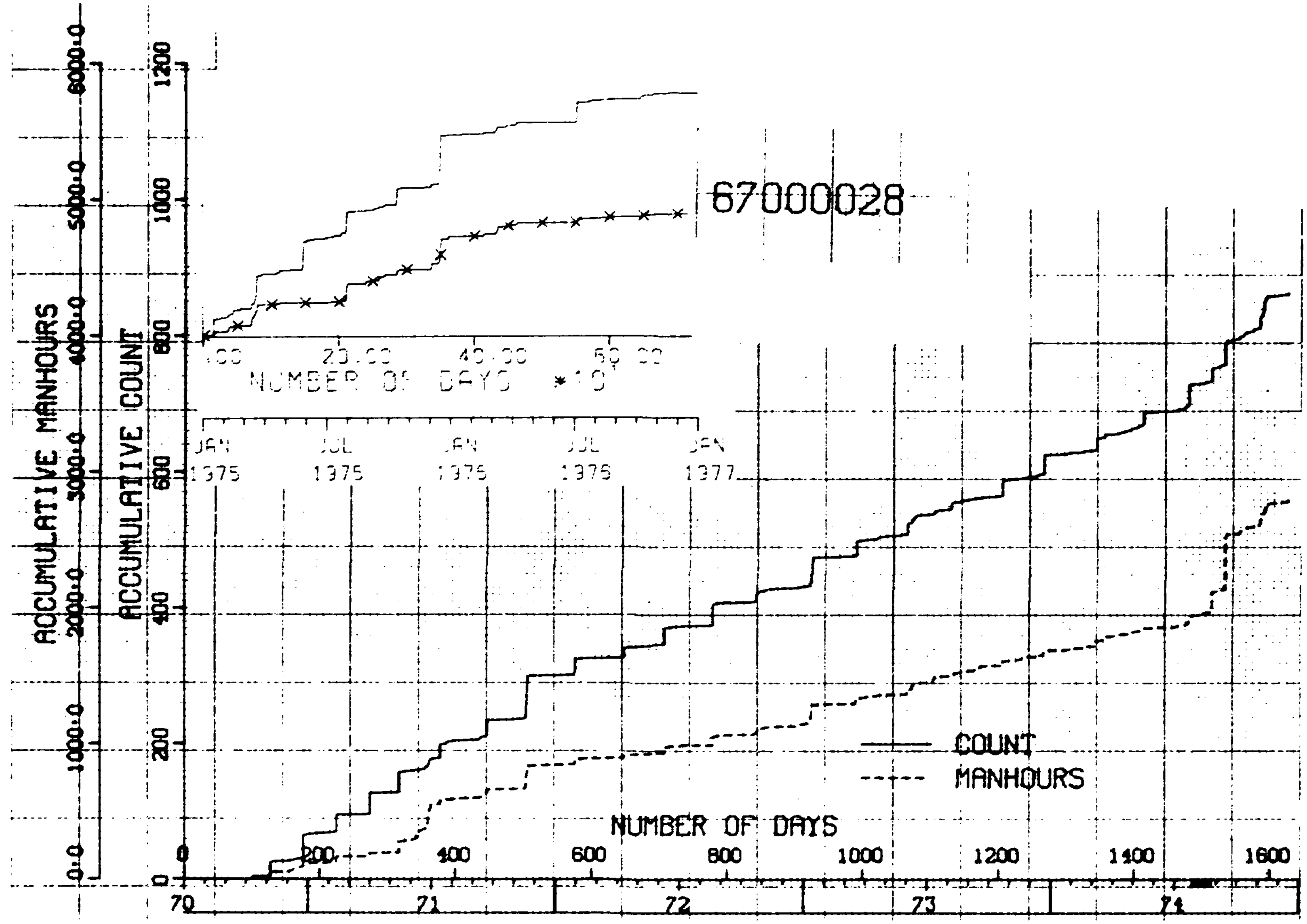

FIGURE 15. C-141A SN 67000028, ASSIGNED CONTINUOUSLY TO CHARLESTON AFB.

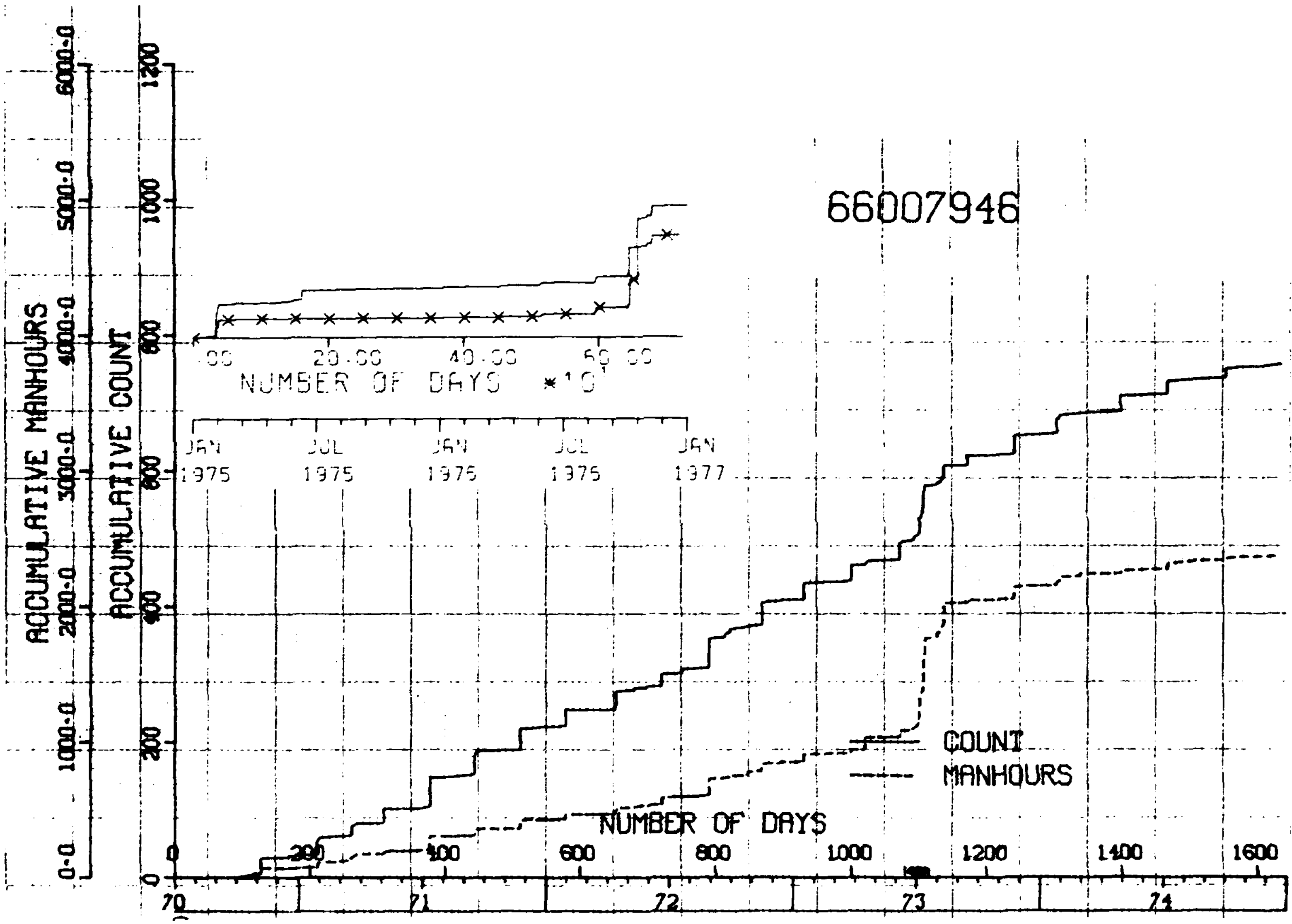

FIGURE 16. C-141A SN 66007946 ASSIGNED CONTINUOUSLY TO NORTON AFB.

region lasting six months or more. Figure 16 does not show such a gap for the first time period, but gaps are present in the records of at least 17 Norton aircraft for this time period. In the second time period, 1975-76 however, nearly every Norton aircraft exibits this anomaly (cf. inset of Figure 16). Twelve other aircraft show data gaps in the first time interval. These aircraft are distributed more or less uniformly among the other airbases and do not appear to result from a systematic problem of either data collection or transmittal to HQ AFLC. The fact that so many airplanes at Norton exhibit data gaps, however, suggests that the Norton Anomaly is base-peculiar. It might be possible to explain the gaps from the first time period as the result of aircraft being away from home station for six months or more. It is more likely, however, that a systematic change in data reporting and/or aircraft maintenance occurred at Norton in the spring or summer of 1974.

The slopes of field maintenance (i.e., organizational-level maintenance), both records and manhours, were measured for each individual aircraft from these charts. These slopes expressed as records per month or manhours per month, per-aircraft(R/M, MH/M) were collected for each airbase and the averages computed. It was noticed that the records for the last two years of the time period 70-74 were somewhat lower than were those for the first two years. This appeared initially to relate to depot maintenance. Accordingly these averages were computed for the time period prior to and for the time following the most recent depot maintenance, and are show in Table 16.

TABLE 16. FIELD MAINTENANCE (ORGANIZATIONAL LEVEL) CORROSION REPAIR RATES PER AIRCRAFT ON C-141A AIRCRAFT BY AIRBASE, 4Q70 to 4Q74.

	Before Most Recent Depot Maintenance				After Most Recent Depot Maintenance			
	Records per Month	Std Dev.	Manhours per Month	Manhours per Record	Records per Month	Std Dev.	Manhours per Month	Manhours Per Record
Altus, OK	11.9	1.7	35.2	3.0	8.7	2.3	28.1	3.2
Charleston, SC	14.7	3	33.9	2.3	14.3	2.2	35.2	2.5
Dover, DE	15.2	2.7	33.8	2.2	12.4	1.5	27.1	2.2
McChord, WA	30.7	2.1	39.4	1.3	11.2	2.6	17.6	1.6
McGuire, NJ	10.6	2.0	28.7	2.7	8.0	1.8	26.5	3.3
Norton, CA	15.4	1.9	29.8	1.9	8.9	2.5	19.6	2.2
Travis, CA	14.4	2.1	52.1	3.6	11.2	2.5	33.8	3.0

Note:
1. This Table is Table 9, p.23 of the Interim Report, 20 May 1976.
2. The "McChord Anomaly" may be noted in Records per Month before most recent Depot maintenance (cf. Figure .) Repair rates were exceptionally high through about the first quarter of CY 1973 and sharply reduced thereafter.
3. The "Norton Anomaly" also may be seen by comparing both Records per Month and Manhours per Month before and after most recent depot maintenance.

These figures show quantitatively the differences between the rate of field maintenance among the several airbases. In the section of Table 16 labeled "before most recent depot maintenance," the McChord Anomaly is apparent, when nearly 31 R/M were reported, compared with only 11 from McGuire AFB. In terms of manhours per month, however, Travis AFB reports the largest volume, 52 MH/M whereas McChord AFB is somewhat lower at 39. It seems that the McChord Amonaly is related to the rate of reporting maintenance actions, i.e. closed out lines on AFTO Form 349. In order to obviate the McChord Anomaly, data following the most recent depot maintenance should be considered. Charleston AFB reported the highest rate, 14 R/M and McGuire AFB the lowest, 8. In manhours per month, Charleston AFB is again highest, 35 MH/M, and whereas McChord AFB reported the lowest figure, 18. These numbers can be used to predict average maintenance actions and maintenance manhours that will be expended on aircraft stationed at these airbases. Although this is simply an extrapolation of prior maintenance activity, it is reasonably accurate. These predicted values will be discussed later.

A number of analyses have been performed on the data to demonstrate that differences in maintenance histories of aircraft are base dependent. All analyses confirm that they are. One particularly effective demonstration are probability curves (4) shown in Figures 17 and 18. In these figures are plotted the corrosion maintenance manhours per quarter of aircraft stationed continuously at five airbases, Travis

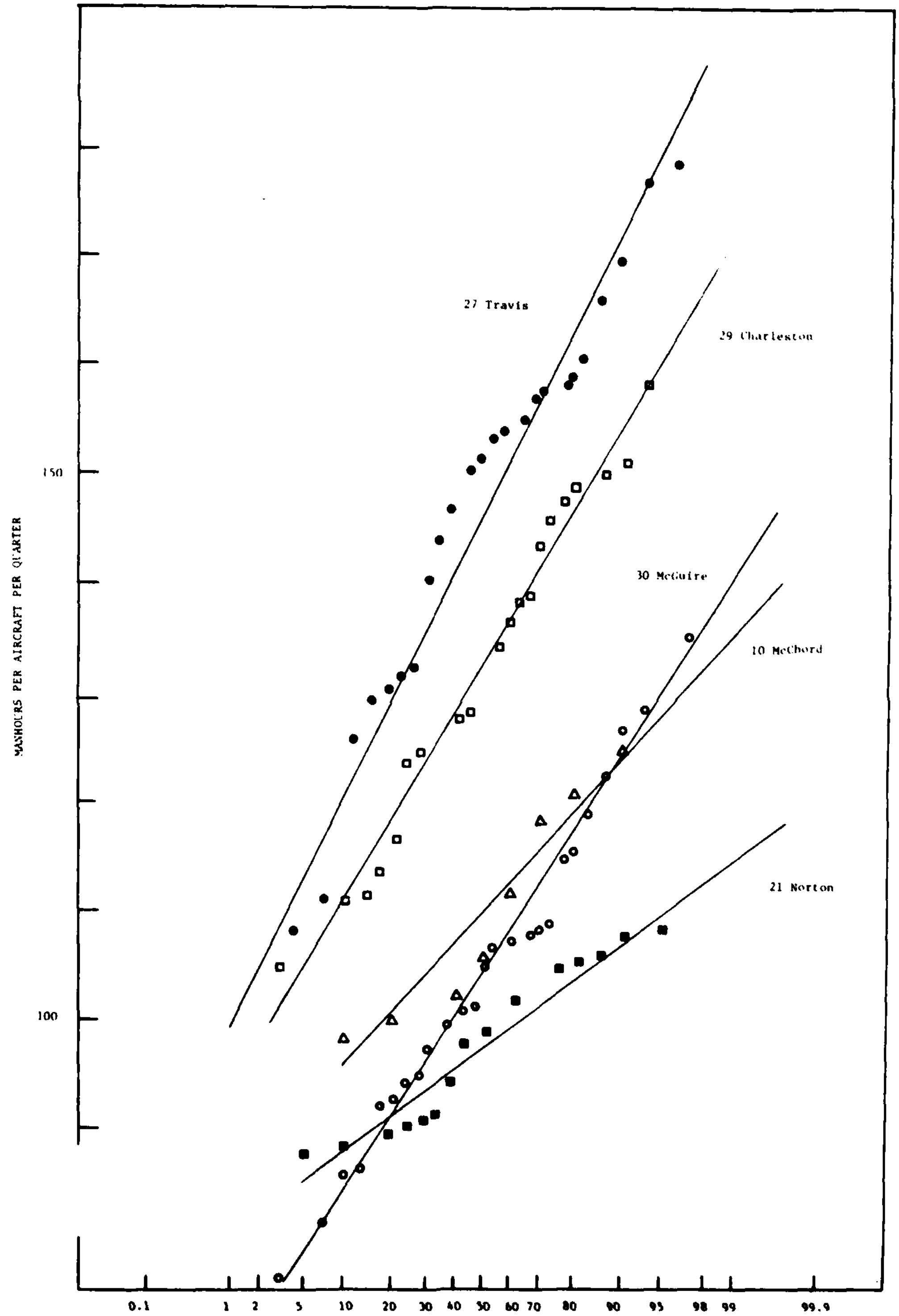

FIGURE 17. DISTRIBUTION OF ORGANIZATIONAL-LEVEL (FIELD) CORROSION MAINTENANCE MANHOURS AMONG AIRCRAFT CONTINUOUSLY ASSIGNED TO AN AIRBASE, 4Q70 to 4Q74. NUMBERS INDICATE SIZE OF SAMPLE.

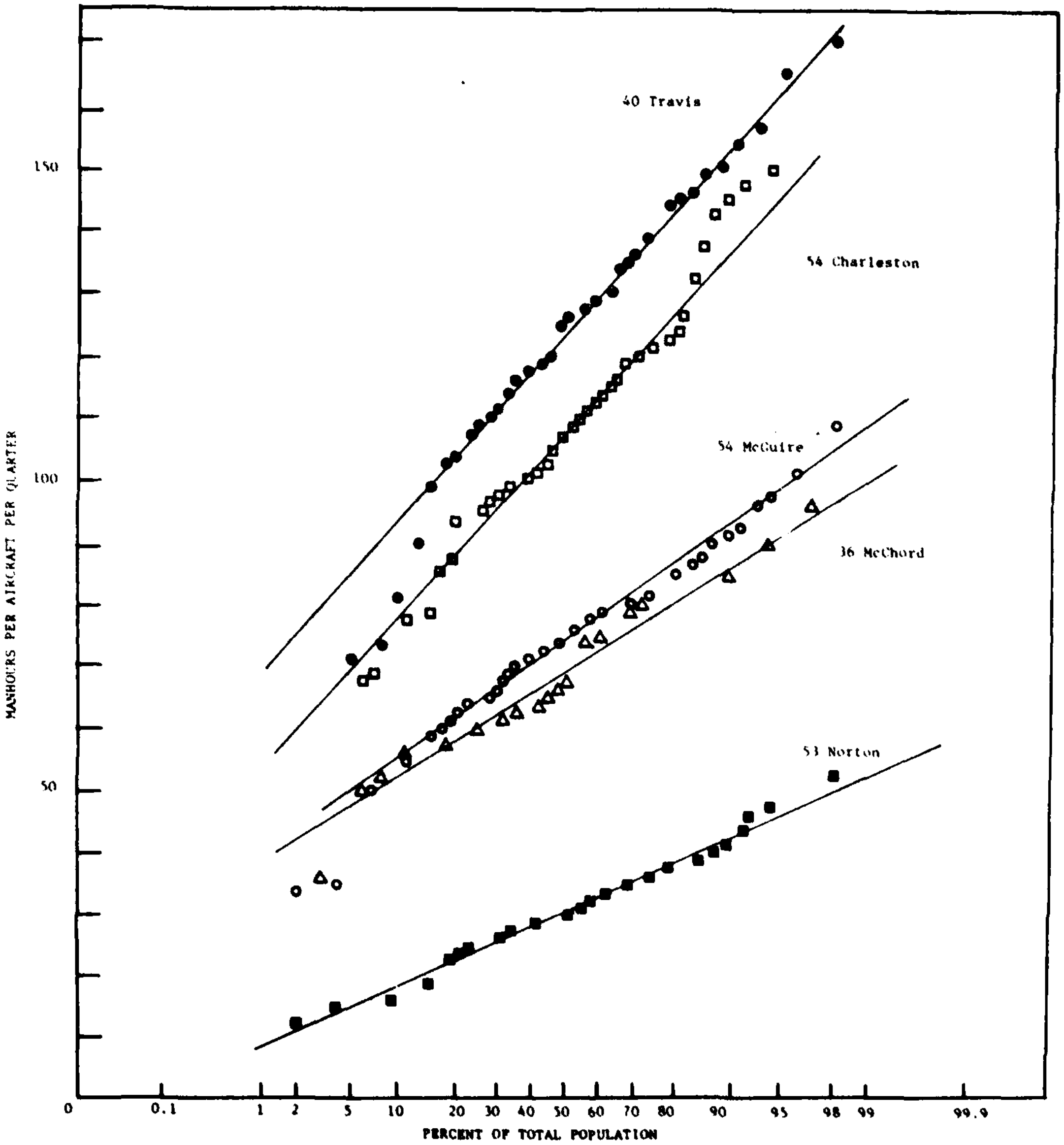

FIGURE 18. DISTRIBUTION OF ORGANIZATIONAL-LEVEL (FIELD) CORROSION MAINTENANCE MANHOURS AMONG AIRCRAFT CONTINUOUSLY ASSIGNED TO AN AIRBASE, 1Q75 to 4Q76. NUMBERS INDICATE SIZE OF SAMPLE.

Charleston, McGuire, McChord, and Norton. The differences between aircraft from each airbase are apparent. The 27 aircraft stationed at Travis AFB show the highest number of corrosion maintenance manhours, whereas 21 aircraft stationed at Norton show the lowest for 1970 through 1974 (Figure 17). It may be seen that the aircraft at Travis AFB for which the fewest maintenance manhours were reported, received more than that aircraft at Norton AFB which received the largest. In other words, the most poorly-maintained airplane at Travis AFB received more manhours of corrosion maintenance than the best-maintained aircraft at Norton AFB. Moreover, the average aircraft at Travis AFB, at the 50% level, received approximately 150 manhours per quarter, a larger maintenance effort than any airplane received at McGuire, McChord, and Norton and more maintenance manhours than 90% of the airplanes received at Charleston AFB. The results are not materially different for the period 1975-1976, as shown in Figure 18. Again the most poorly-maintained airplane at Travis received more maintenance manhours than the best-maintained aircraft at Norton AFB. One must remember, of course, that the maintenance manhours reported for Norton AFB will reflect the Norton Anomaly. Collected in Table 17 are mean values for the maintenance manhours from Figure 17. Also shown in Table 17 are the difference in means between bases.

In Figure 17 the data for each base seemed to fit a normal distribution reasonably well. A chi-square test shows that this conjecture is just at the verge of significance.

TABLE 17. C-141A ORGANIZATIONAL-LEVEL (FIELD) CORROSION MAINTENANCE MANHOURS: DIFFERENCES IN MEANS BETWEEN BASES, 4Q70-4Q74.

	Travis $\bar{X}$=138.2	Charleston $\bar{X}$=123.5	McChord $\bar{X}$=98.8	McGuire $\bar{X}$=94.1	Norton $\bar{X}$=87.1
Travis $\bar{X}$=138.2	0	14.7* (9.8)	39.4*	44.1*	51.1*
Charleston $\bar{X}$=123.5		0	24.7* (7.4)	29.4*	36.4*
McChord $\bar{X}$=98.8			0	4.7 (6.2)	11.7* (4.9)
McGuire $\bar{X}$=94.1				0	7.0* (6.0)
Norton $\bar{X}$=87.1					0

Notes: 1. *significant at ≤5% level.

2. Values are manhours per Aircraft per quarter.

3. Entries without parentheses: Observed difference.
Entries between parentheses: Maximum expected difference (α = 0.5).

To test for possible artifacts, a check for randomness of final digits in the manhours was made; a chi-square test confirms this conjecture. Hence, we believe that use of the t-test is justified.

Table 17 presents the results of a t-test for the sigfincance of difference between means for the data of Figure 17. The estimate for the mean is given at the borders of the table under the name of each base. The difference in means calculated from numbers is given in table as an entry without parentheses. The minimum difference between the respective means for significance at the 5% level is given underneath the observed estimate as a number within parentheses. The difference in means is significant, (as indicated by an asterisk) in all cases except McChord/McGuire. We conclude therefore that maintenance records as reported into the MDC system from one airbase to another are indeed characterized by different means in field corrosion-maintenance manhours for the period 4Q70-4Q74.

Table 18 presents the results of a t-test for significance of the difference between means for the data of Figure 17 and 18. For the two periods under consideration there are listed for each base the number of aircraft N, the observed mean $\overline{X}$, the standard deviation s, and the coefficient of variation CV = 100 $(s/\overline{X})$%. Under "comparison" are listed the observed difference between means for the two time periods $(\Delta,\overline{X})_O$; the minimum difference in this quantity expected at the 5% level of significance; and the significance according to this standard by an asterisk for a real but reasonable difference, and by

TABLE 18. C-141A ORGANIZATIONAL-LEVEL (FIELD) CORROSION MAINTENANCE MAN-HOURS: COMPARISON OF DATA FROM 4Q70-4Q74 and 1Q75 to 4Q76.

	4Q70-4Q74				1Q75-4Q76				Comparison		
Base	N	$\bar{X}$	s	CV	N	$\bar{X}$	s	CV	$(\Delta\bar{X})_o$	$(\Delta\bar{X})_m$	Sig.
Travis	27	138.2	18.8	14%	40	124.0	24.0	19%	14.2	10.5	*
Charleston	29	123.5	17.3	14%	54	107.5	23.8	22%	16.0	9.1	*
McChord	10	98.8	5.6	6%	36	69.3	13.5	19%	29.5	5.8	(!)
McGuire	30	94.1	15.6	17%	54	82.8	15.1	18%	11.3	6.5	*
Norton	21	87.1	7.4	8%	21	30.4	9.6	32%	56.7	4.2	(!!)

$\bar{X}$ = observed mean

s = observed standard deviation

CV = observed coefficient of variation = $\bar{X}/s$

$(\Delta\bar{X})_o$ = observed difference between old data and new data at a given base

$(\Delta\bar{X})_m$ = maximum difference expected at 5% level

* = significant at 5% level or better

(!) = discrepancy so large as to demand attention beyond statistical analysis

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exclamation points to show that some completely new factor is surely at hand.

These differences in rate of field maintenance from one airbase to another also are visible in the graphs of comulative maintenance of aircraft which have been transferred from one base to another (cf. Figure 10). Several examples are shown in Figures 19 through 25. The change in slope is most evident in the repair records curve and less obvious in the manhours curve. Figure 19 shows the dramatic change in maintenance which occured when the aircraft was transferred from McChord AFB to Altus AFB. Figure 22 shows the change in field-maintenance rate corresponding to a transfer between McGuire AFB and Altus AFB, which both reported nearly the same low rate of field maintenance. Figures 23 and 24 show converse examples of aircraft transferred from McChord to Travis, and from Travis to McChord respectively. Finally Figure 25 shows the maintenance rate changes of an aircraft transferred first from McChord to Travis and then from Travis back to McChord. The chart dutifully shows the McChord Anomaly followed by a typical Travis pattern, and succeeded again by the McChord Anomaly. It is clear the the level of field-level maintenance does vary from one airbase to another. Hence, the most important factor in determining the level of field corrosion maintenance, as documented in the AFM 66-1 MDC system records, is the airbase to which the aircraft is assigned.

We would like to infer from these base-to-base variations that the different levels of maintenance activity reported

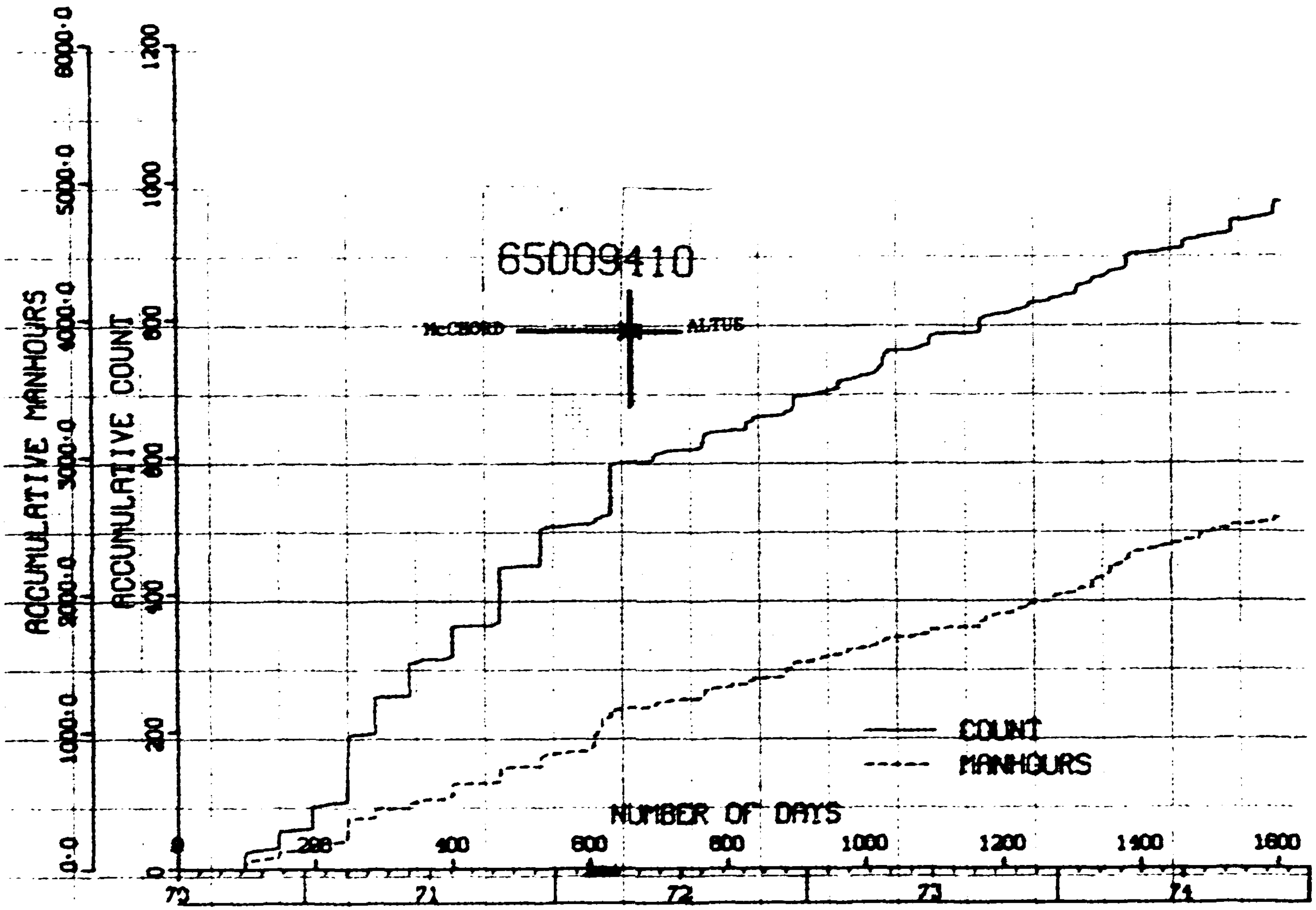

FIGURE 19. C-141A SN 65009410, TRANSFERRED FROM McCHORD AFB TO ALTUS 20 1972.

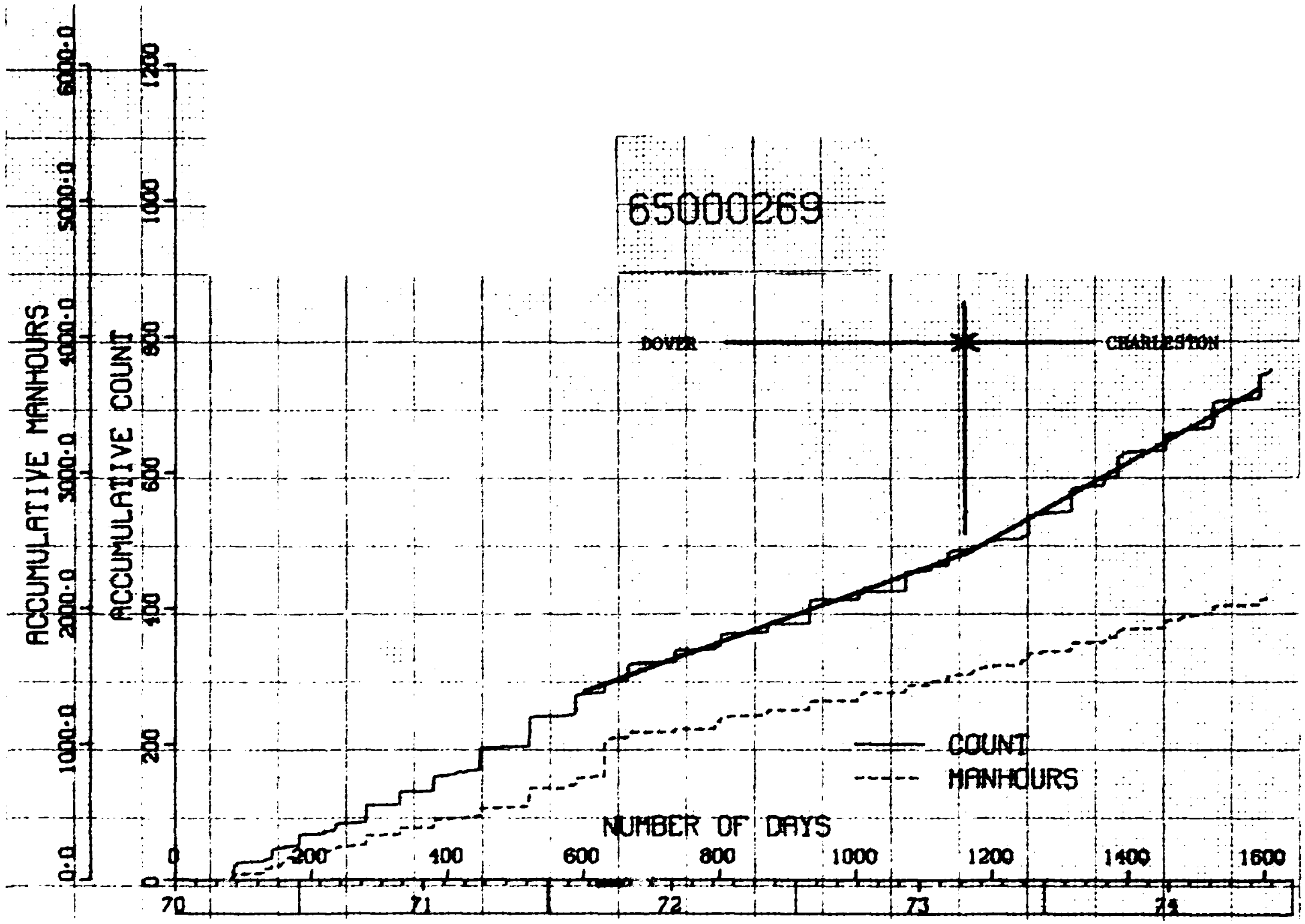

FIGURE 20. C-141A SN 6500269, TRANSFERRED FROM DOVER AFB TO CHARLESTON AFB, 4Q 1973.

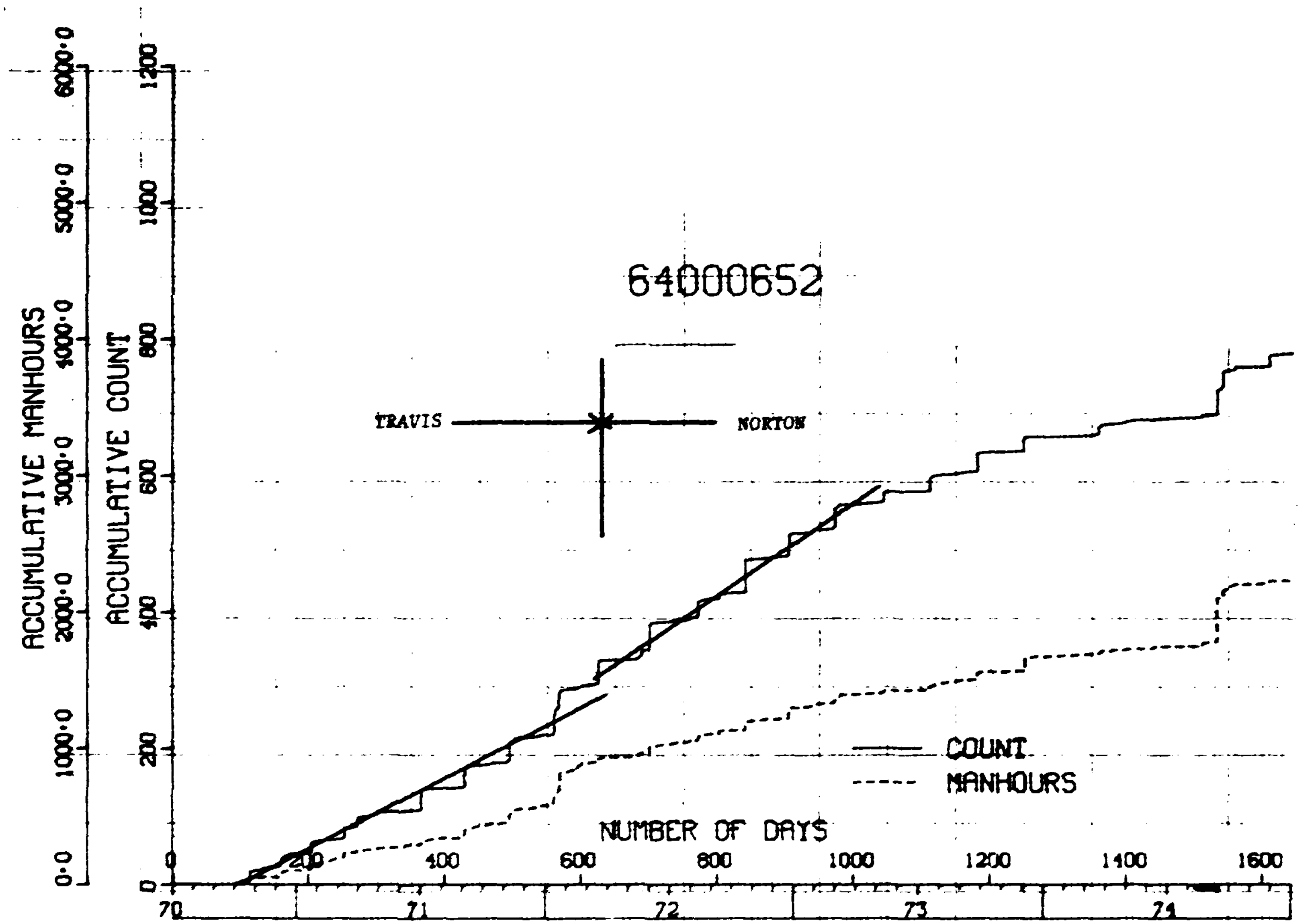

FIGURE 21. C-141A SN 64000652, TRANSFERRED FROM TRAVIS AFB TO NORTON AFB, 2Q 1972. NOTE DATA GAPS BEGINNING LATE 1973.

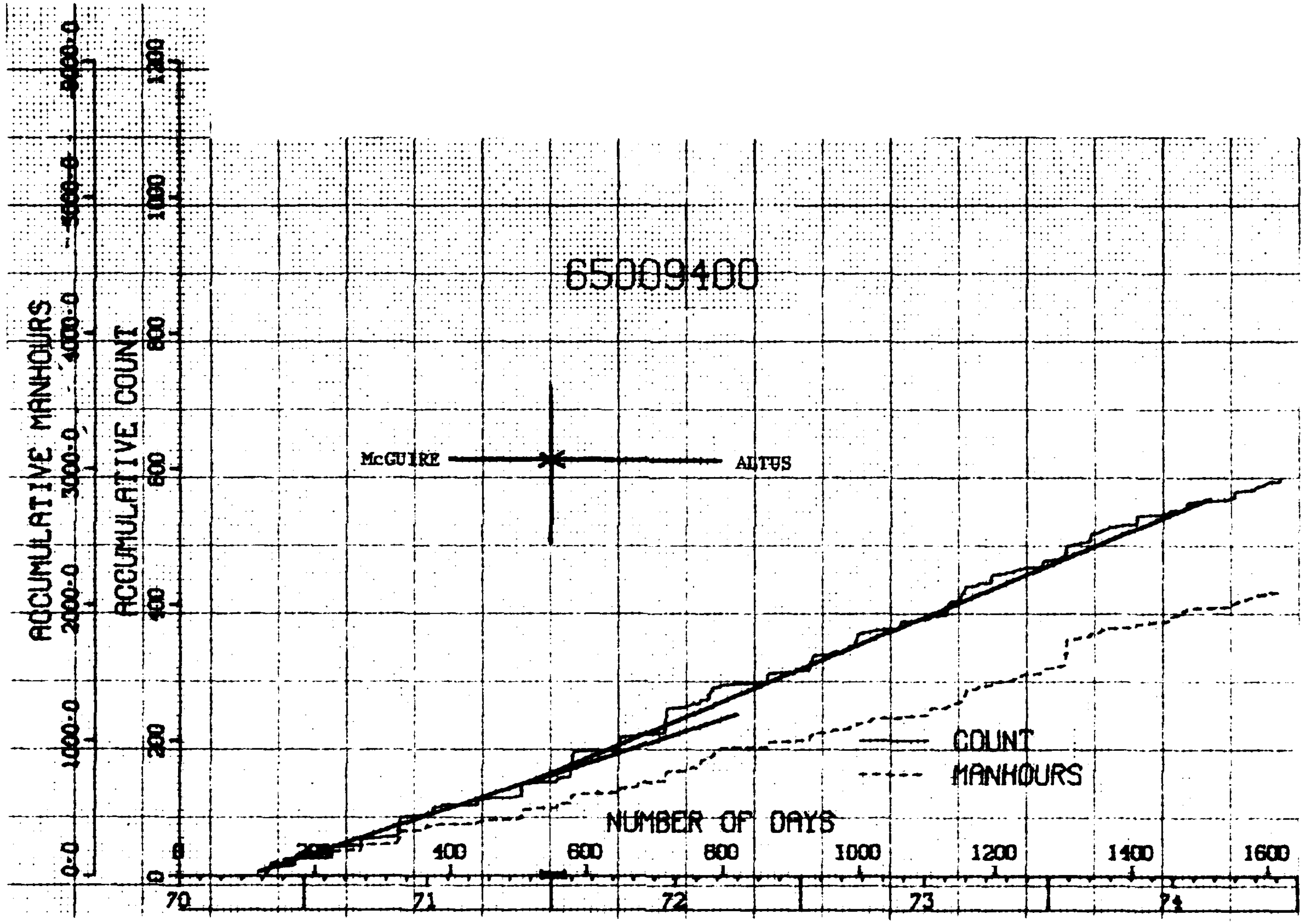

FIGURE 22. C-141A SN 65009400, TRANSFERRED FROM McGUIRE AFB TO ALTUS AFB, 1Q 1972 FOLLOWING PDM.

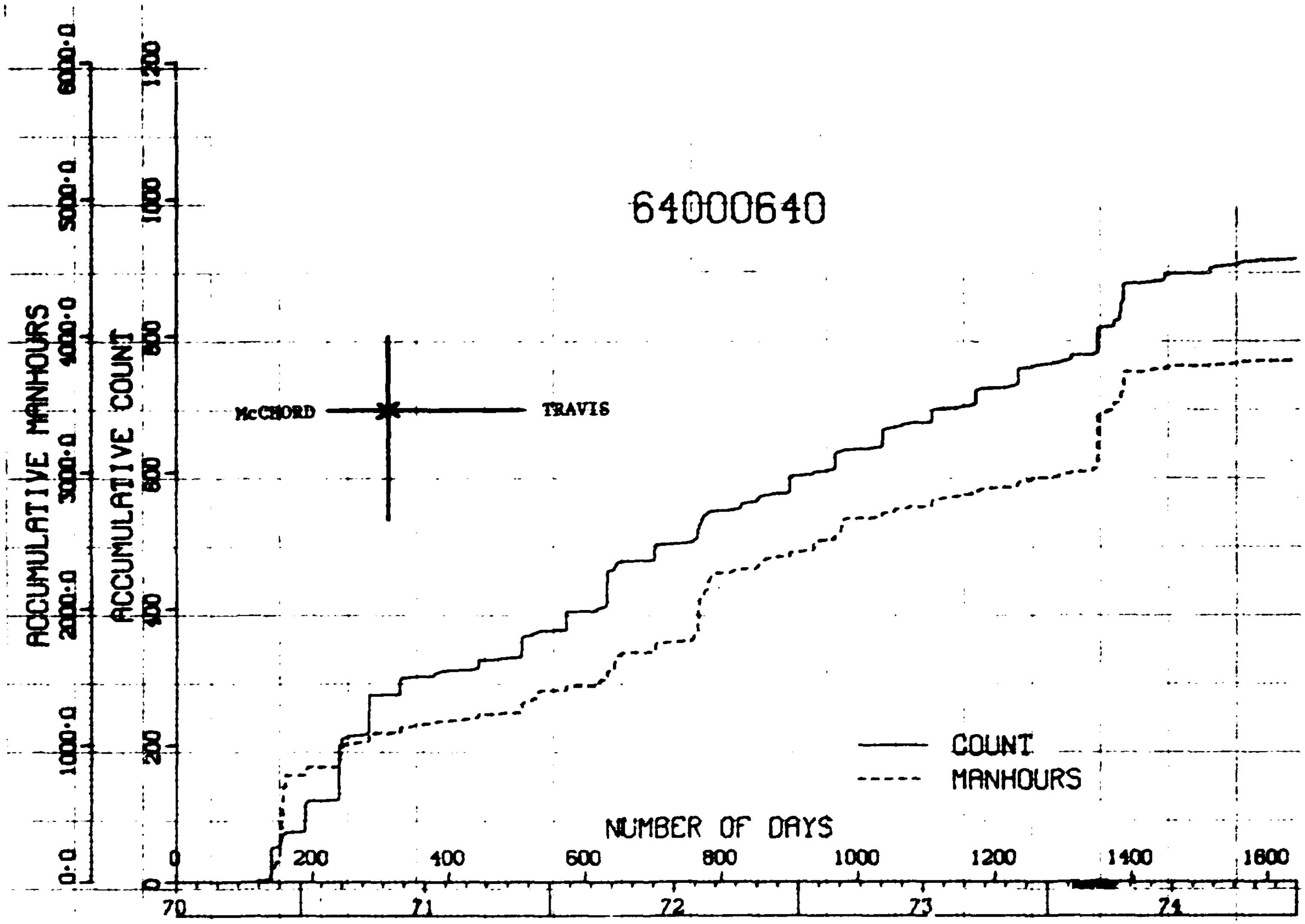

FIGURE 23. C-141A SN 64000640, TRANSFERRED FORM McCHORD AFB TO TRAVIS AFB, 2Q 1971.

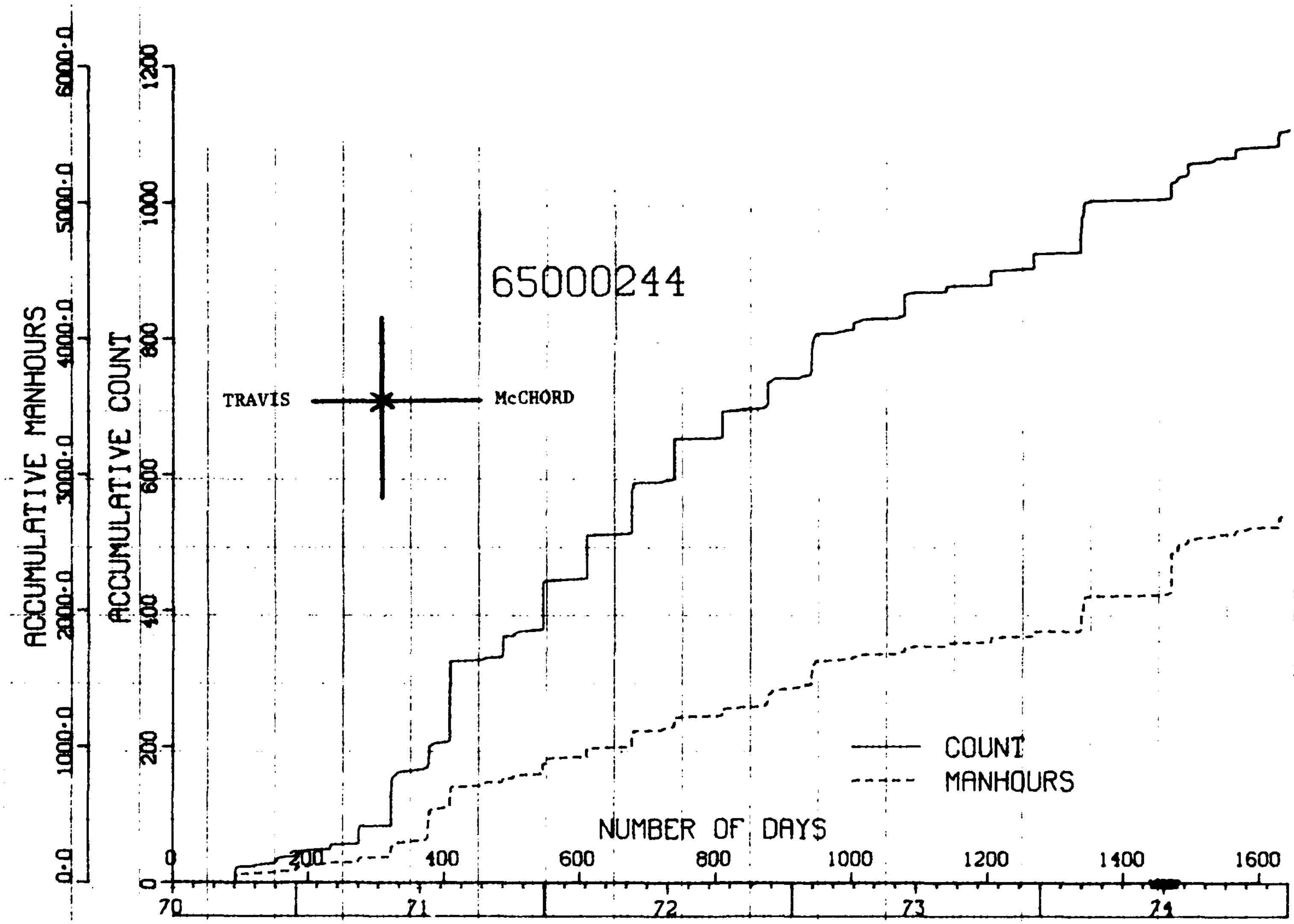

FIGURE 24. C-141A SN 65000244, TRANSFERRED FROM TRAVIS AFB TO McCHORD AFB 2Q 1971.

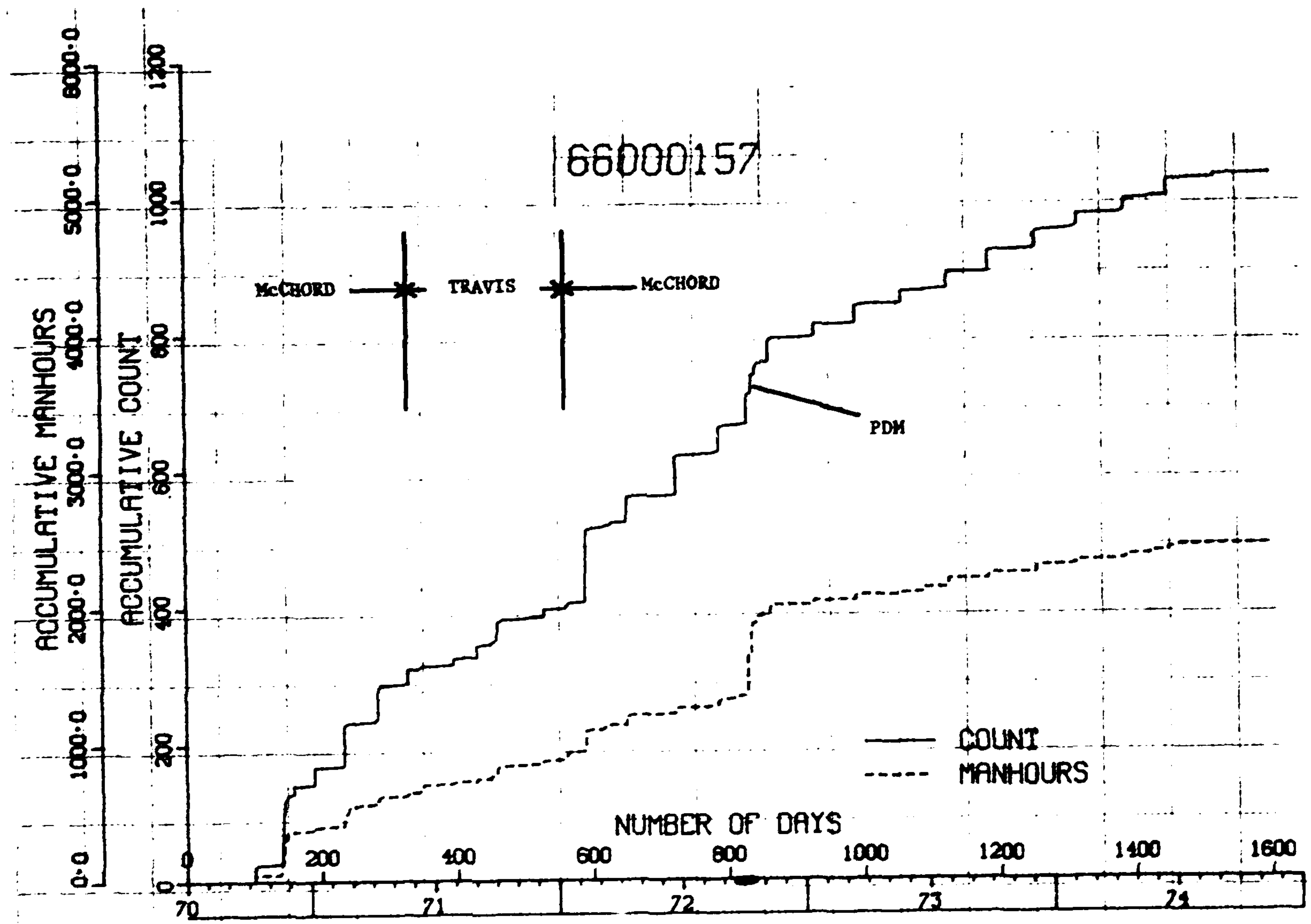

FIGURE 25. C-141A SN 66000157 TRANSFERRED FROM McCHORD AFB TO TRAVIS AFB 2Q 1971 AND BACK TO McCHORD AFB 4Q 1971. NOTE SHARP DECREASE IN RATE OF FIELD MAINTENANCE FOLLOWING PDM IN 1972.

reflect a difference in the corrosive severity of the environment at each airbase. It should be possible to compute from these differences in maintenance activity a corrosion-severity index for each base. One then would compare such a computed corrosion-severity index with those obtained from the Pacer Lime program.

There are unfortunately, several problems with this simplistic approach, attractive as it may be. First, aircraft transferred from one base to another immediately exhibit the maintenance fingerprint of the new base. If an aircraft had been stationed at a base of low corrosion-severity, then its corrosion-damage condition should be relatively lower than its new companion aircraft. One would expect that there should be an induction period before the airplane shows accelerated corrosion in the new environment and during which the corrosion maintenance repairs remain relatively low compared with other aircraft at the new base. As noted above this does not occur; there appears to be no induction period.

Second, at most bases the rate of field maintenance declined near the end of 1972, as shown in Table 17 and in the cumulative maintenance charts. Such a decline in field maintenance rate may have resulted from a change of mission, such as decreased operations in South East Asia. It would not be consistent however with a simultaneous change of corrosion severity at all bases. Since this decline in rate of field maintenance is observed at all MAC airbases except Charleston AFB, it does not appear likely that it can be correlated with

the decline in South East Asia operations. Most of the SE Asia support missions were flown out of a few airbases, not from all of them. It is more likely that their decline resulted from changes in the procedures for collecting and reporting maintenance data.

The argument has been advanced that the rate of field maintenance reflects the enthusisam with which respective crews or commanders at a particular airbase pursue corrosion repair work. If this is the case one might expect that aircraft maintained at an "aggressive" base might appear to be in better condition corrosion-wise than aircraft stationed at another base where corrosion maintenance is of lower priority. On the other hand if the field-maintenance rate actually measures the extent of corrosion damage experienced, then one might interpret a higher maintenance rate as being indicative of the higher effort required to maintain aircraft at a specified condition. In that case, aircraft at the higher-maintenance-rate base should be about in the same condition as aircraft at a low-maintenance-rate base.

An impartial measurement of the condition of all aircraft by an unbiased third party would be useful. Such an impartial evaluation is available from the maintenance histories of depot maintenance. Since depot maintenance is effected by the same personnel at Robins AFB on all C-141A aircraft, it is reasonable to assume that they would treat all aircraft equally and that there should be no variations in reporting data. Accordingly we turn now to an analysis of the corrosion-

maintenance of the aircraft effected at Robins AFB in PDM before completing the examination of field-level data.

SECTION VII

DEPOT MAINTENANCE HISTORIES

Corrosion repairs and associated manhours were separated from the main data base for independent study. These records are identifiable as those bearing the location code YKHT and which are dated within the specified PDM time period by serial number. Aircraft serial numbers must be subgrouped further according to the fiscal year in which depot maintenance is effected because the effort varies from one year to another in both nature and extent (29).

There are two additional sets of special cases: Analytical Condition Inspection (ACI) and Controlled Interval Extension (CIE) aircraft. The first set are about twelve aircraft selected each year as a "cross section of the fleet...using age, base assignment and months since last PDM as criteria." (19,20) These aircraft are subjected to a more thorough inspection at depot in order "to uncover hidden defects that are not detectable through normal inspection programs." The results are used to determine what changes are appropriate to the various inspection packages and intervals, to uncover problem areas on the aircraft, and to assess the overall condition of the force.

The CIE aircraft, also numbering about a dozen, receive depot maintenance after a longer time. Currently the extended interval is 48 months but it was 42 months in 1972. The purpose of extending the depot maintenance interval is to determine the likely consequence of longer intervals for the entire force. Actual normal intervals are a compromise among several factors, including the high cost of depot maintenance,

suspected and actual deterioration of the aircraft system, and overall force effectiveness. It is assumed that CIE aircraft are selected according to criteria like those used for ACI aircraft. No details are available, however.

The ACI and CIE programs are two distinct experiments. The first is to learn the nature of potential problems not detected in normal inspections. The second asks what is the impact of depot-maintenance interval on aircraft deterioration. Good scientific practice dictates separation of the experiments by applying them to different populations. Unfortunately, it has been too great a temptation to look carefully (ACI) at the CIE aircraft, with the result that the data are thoroughly mixed. Shown in Table 19 are the distributions of aircraft among the ACI and CIE programs by airbase and fiscal year. (ACI data are lacking for FY72 and 77.) It is not clear from this table how the CIE and ACI sets are in fact representative of the force. The differences in rate of field-level maintenance, as revealed by this study, suggest that additional criteria might be used to select these experimental groups of aircraft.

Analysis of depot manhours and repair record totals reveals no consistent relationship with any parameter. The distribution is random for the entire population and for any subset there of.

Figure 26 shows the distribution of depot-level corrosion maintenance manhours for FY 1973 among aircraft which originated from McGuire, Charleston, and Norton AFBs. Figure 27 shows the distribution for FY 1974 among McGuire Charleston, Travis and Norton AFB aircraft. Both of these figures are linear

Table 19. Distribution of C-141A Aircraft Among Analytical Condition Inspection (ACI) and Controlled Interval Extension (CIE) Programs by Airbase and Fiscal Year.

	FY72	FY73	FY74	FY75	FY76	FY77
ACI Aircraft*						
Altus		0	1(1)	0	1(0)	
Charleston		0	1	2(2)	2(1)	
McChord		1(1)	3(2)	3(1)	2(2)	
McGuire		1(1)	1(1)	1(0)	3(2)	
Norton		0	0	1(1)	1(1)	
Travis		2(1)	1	4(3)	2(1)	
CIE Aircraft**						
Altus	1	0	0	0	0	3
Charleston	2	0	0	2	1	1
McChord	0	1	2	1	2	2
McGuire	4	1	1	0	1	3
Norton	0	1	0	1	1	2
Travis	0	2	0	3	1	2
Totals	8(3)	8(5)	13(7)	13(7)	13(7)	13(5)

*Values in parentheses are interface with CIE program.

**Values in parentheses are interface with ACI program.

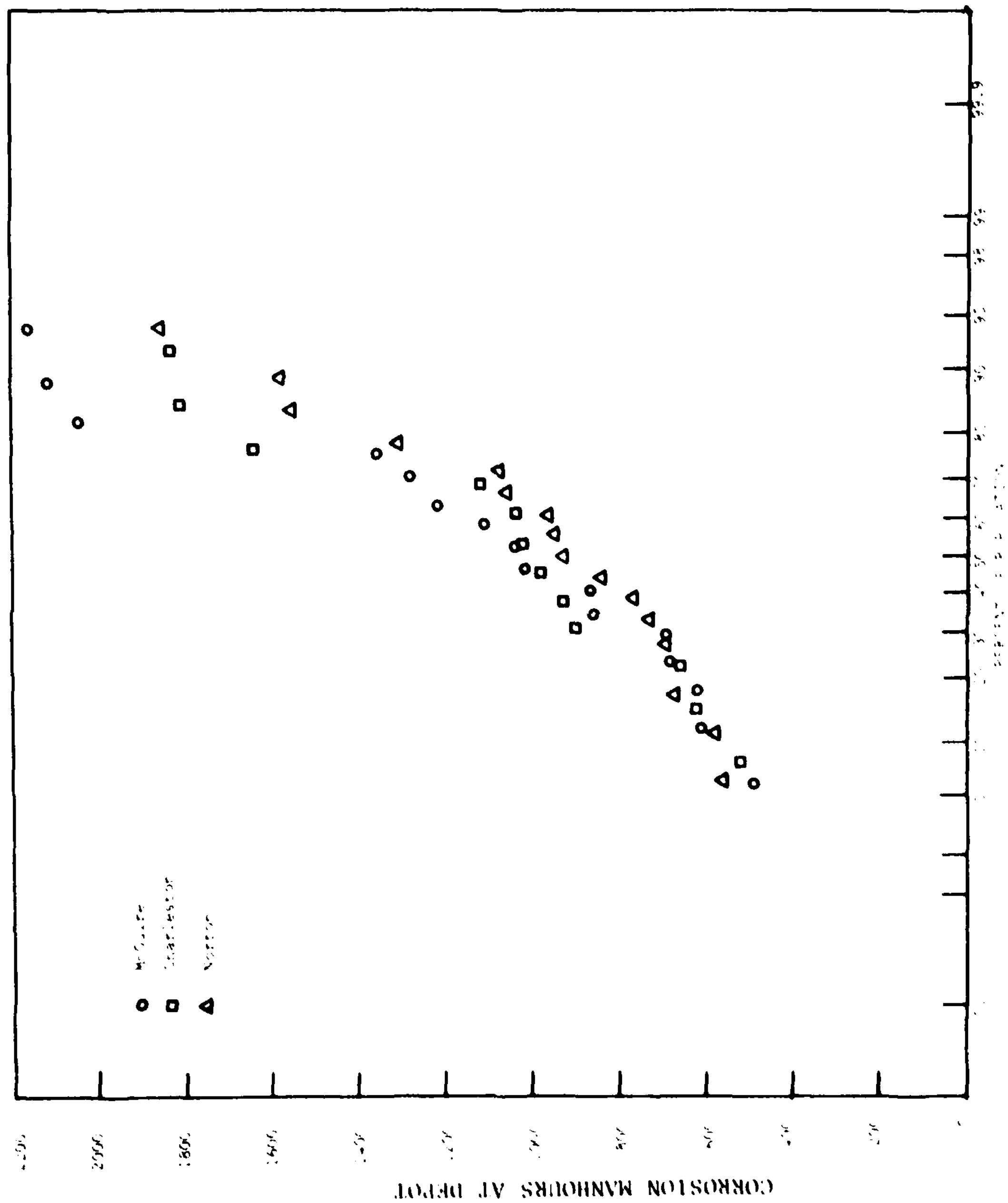

FIGURE 26. DISTRIBUTION OF DEPOT-LEVEL CORROSION MAINTENANCE MANHOURS AMONG AIRCRAFT, FY73.

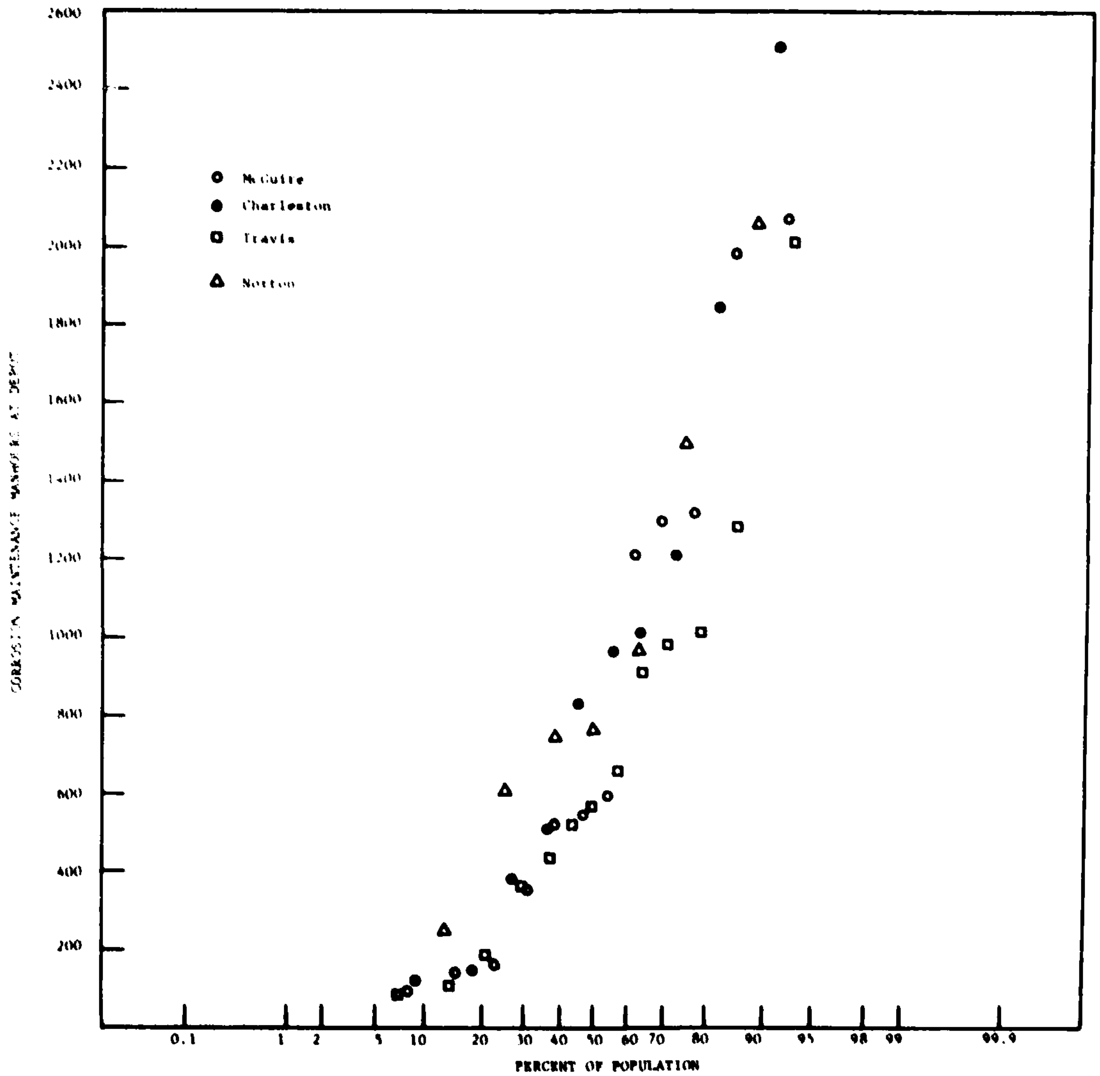

FIGURE 27. DISTRIBUTION OF DEPOT-LEVEL CORROSION MAINTENANCE MANHOURS AMONG AIRCRAFT, FY74.

probability plots. Whatever the differences that exist between these aircraft with respect to corrosion maintenance effected upon them, they are not obviously separable according to the airbase from which they originated, as was true for Figures 17 or 18.

The curvature in the probability plots demonstrates that a normal distribution is not a good approximation, and suggests that a logarithmic-normal plot be tried. This technique provides a somewhat better fit, and accordingly the data for Fiscal Years 1972, 1973, and 1974 were plotted on logarithmic probability paper (maintenance manhours on a logarithmic scale versus cumulative percentages of aircraft on probit scale) in Figures 28, 29, and 30, respectively.

The improvement in fit justifies an attempt at analysis of the data for differences among bases and for yearly trend. Table 20 lists parameters derived from Figures 28, 29, and 30, plus similar data (not shown) for FY 75. The figure within parentheses in the lower lefthand corner of each box is the logarithmic mean of the manhours per aircraft for the base and year as labeled. The other values within the box are logarithms of parameters used in statistical analysis. The results are perhaps more easily grasped if one looks just at the averages mentioned, as plotted logarithmically in Figure 31 against Fiscal Year. Apart from Norton, which displays a remarkably small variation from year to year, the bulk of the bases show a strong rise--by a factor of two or three--from FY 72 to FY 73 followed by a somewhat less steep decline from FY 73 to FY 74,

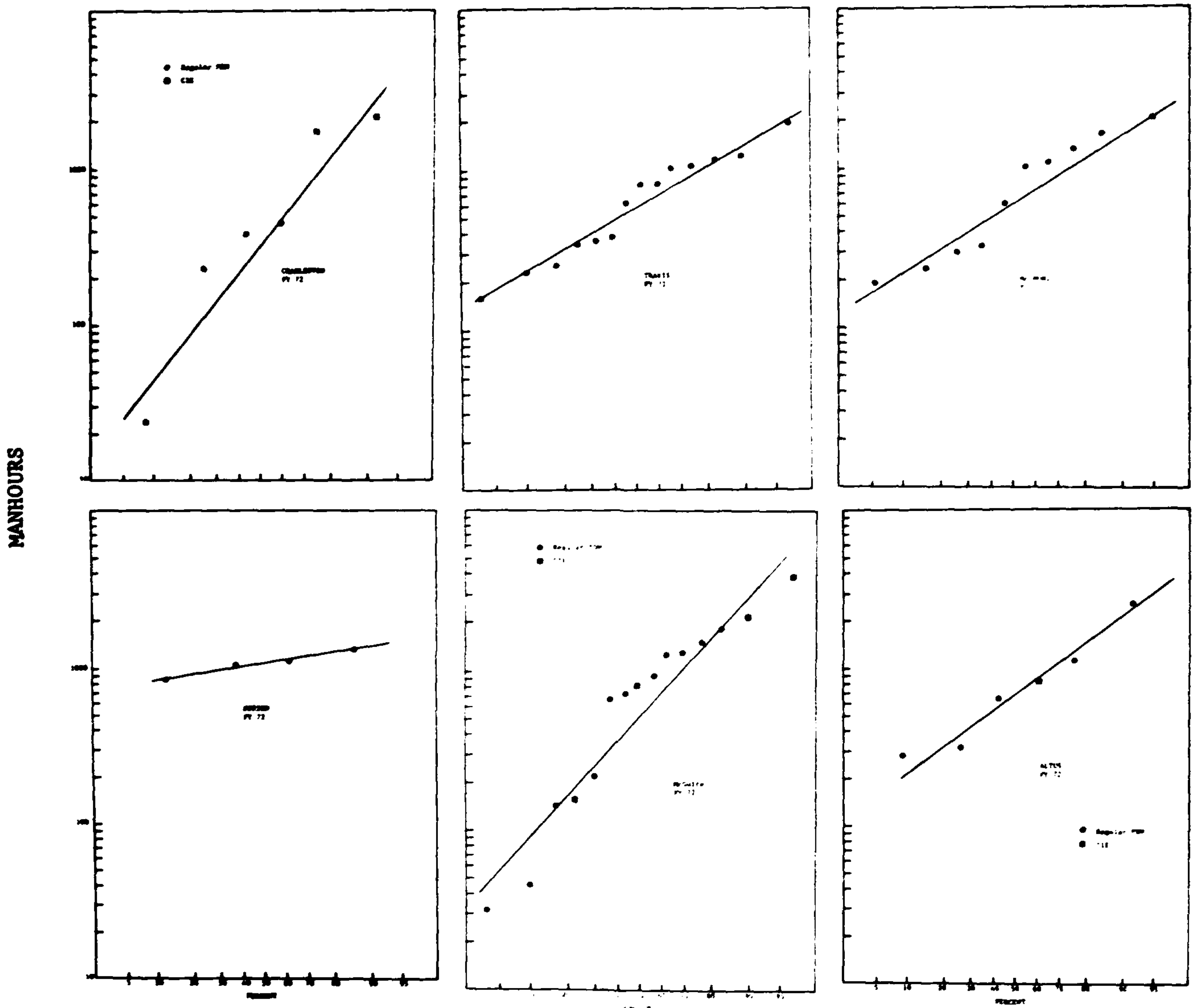

FIGURE 28. DISTRIBUTION OF DEPOT-LEVEL CORROSION MAINTENANCE MANHOURS BY ORIGINATING AIRBASE, FY72.

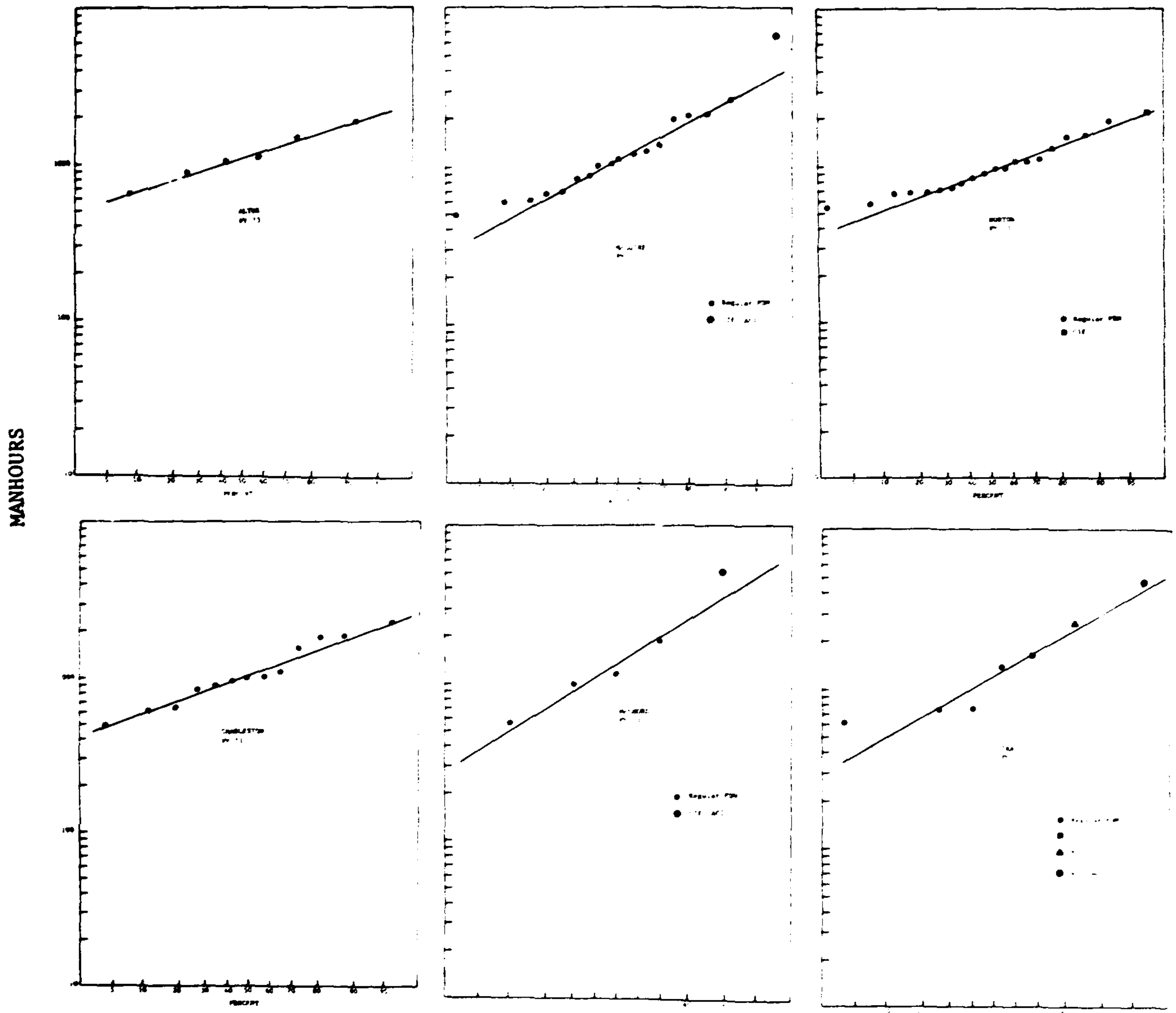

FIGURE 29. DISTRIBUTION OF DEPOT-LEVEL CORROSION MAINTENANCE MANHOURS BY ORIGINATING AIRBASE, FY73.

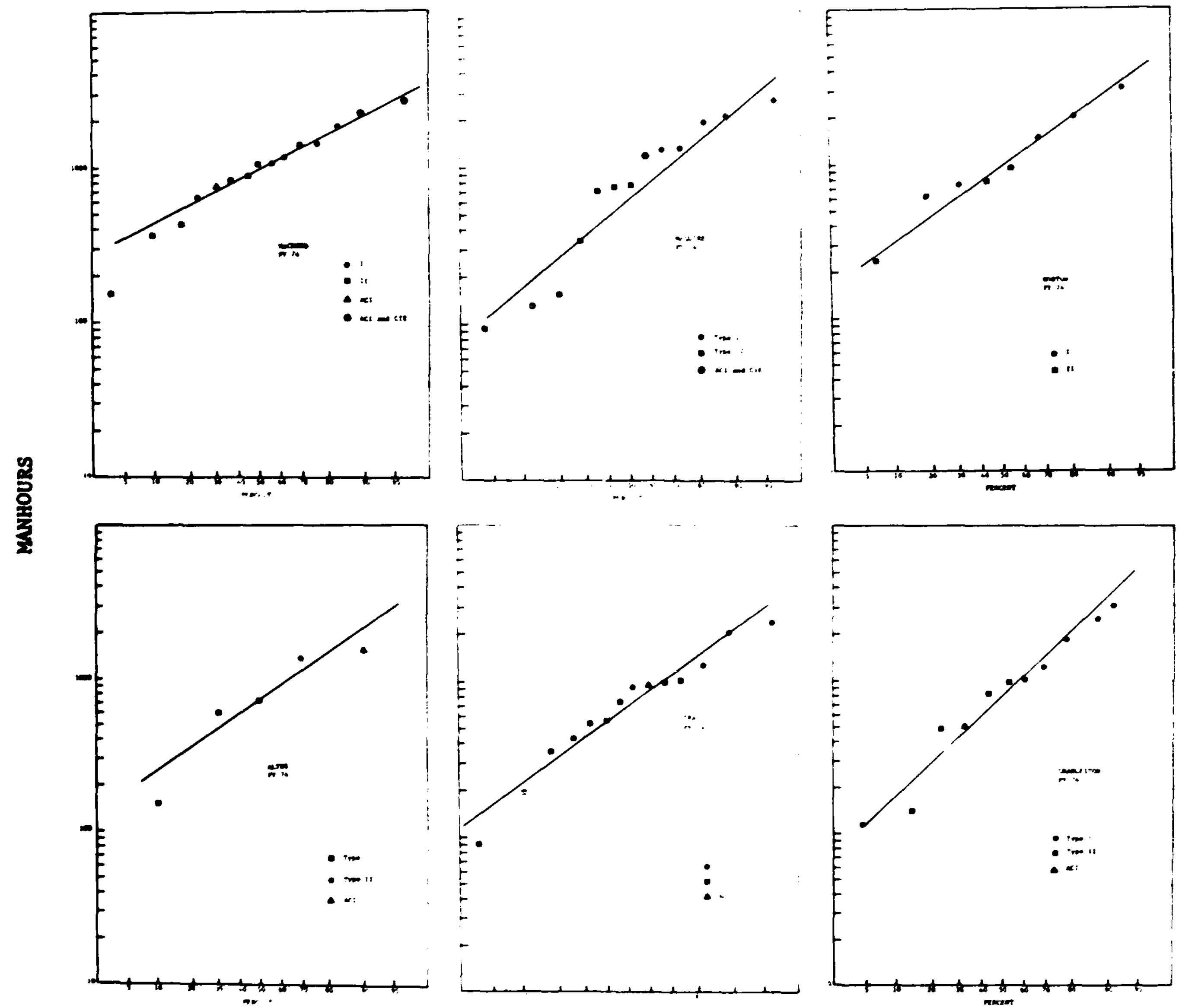

FIGURE 30. DISTRIBUTION OF DEPOT-LEVEL CORROSION MAINTENANCE MANHOURS BY ORIGINATING AIRBASE, FY74.

TABLE 20. C-141A DEPOT-LEVEL CORROSION MANHOURS BY AIRBASE AND FISCAL YEAR.

Year / Base	FY72 log $\bar{X}$	FY72 "log s"	FY73 log $\bar{X}$	FY73 "log s"	FY74 log $\bar{X}$	FY74 "log s"	FY75 log $\bar{X}$	FY75 "log s"
Travis	2.83 (676)	0.11	3.11 (1288)	0.31	2.85 (708)	0.40	2.86 (724)	0.33
Charleston	2.51 (324)	0.67	3.01 (1023)	0.19	2.90 (794)	0.51	2.35 (224)	0.67
McChord	2.78 (603)	0.31	3.12 (1308)	0.33	2.94 (871)	0.25	2.69 (490)	0.29
McGuire	(2.72) (368)	(0.59)	3.04 (1096)	0.28	2.79 (617)	0.42	2.30 (200)	0.64
Norton	3.03 (1072)	0.07	2.97 (933)	0.19	2.98 (955)	0.38	2.40 (794)	0.42
Altus	2.85 (708)	0.33	3.04 (1096)	0.17	2.85 (708)	0.35	--	--

Note: Values in parentheses are manhours per aircraft.

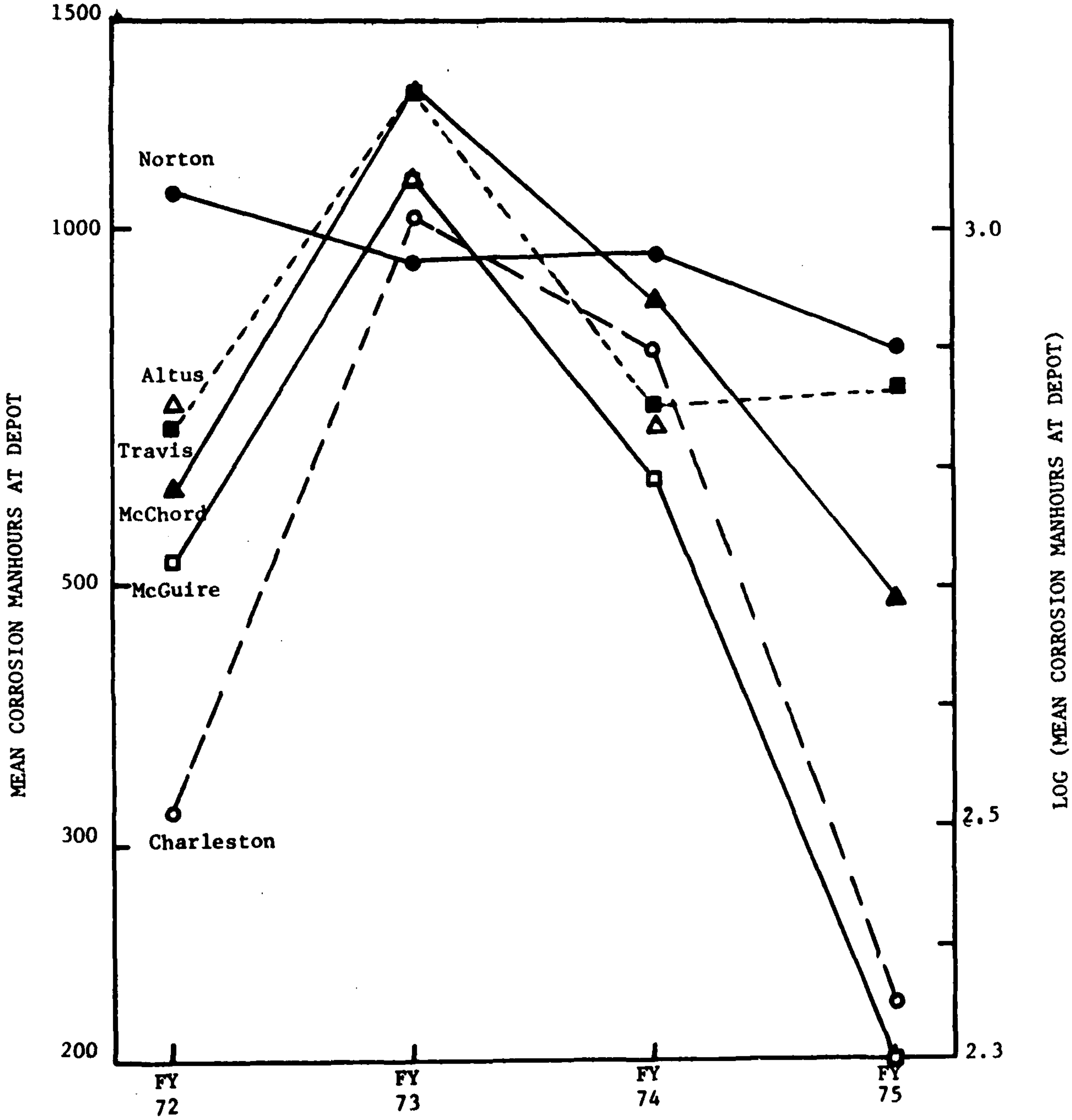

FIGURE 31. C-141A CORROSION MAINTENANCE MANHOURS (MEAN) AT DEPOT, BY AIRBASE.

and by another decline from FY 74 to FY 75 (with the exception of Travis, which rises insignificantly, and possibly of Altus, for which data are not available). This trend with Fiscal Year is undoubtedly the result of differences in maintenance package and, perhaps, reporting, and one is hard put to impute it to any change in corrosion rate, aircraft aging, or weather variations. The ranking among bases does not persist between years, and again it is hard to infer any important assertions, apart from the Norton Anomaly.

To test for possible correlation between field maintenance and depot maintenance, either positive or negative, scatter diagrams (i.e, plots of depot manhours vs. field-level manhours and depot records vs. field-level records, by serial number) were made for FY 73, 74, 75. Few data were available for FY 73, and no conclusions can be drawn. For FY 74 and FY 75, the scatter diagrams suggest, and an analysis confirms that there is no correlation between either depot count and field count or depot manhours and field manhours.

Some have held (19, 20) that extending the PDM interval results in disproportionately greater damage, hence greater maintenance costs and reduced force effectiveness. From this and other considerations, the interval is believed to be optimized at 36 months. Corrosion maintenance records at depot support this view weakly, if at all. Shown in Figures 32 to 37 are the total maintenance records and manhours effected at depot on individual aircraft for FY 72, 73, and 74 versus PDM interval. In addition, for the latter two years the ACI aircraft

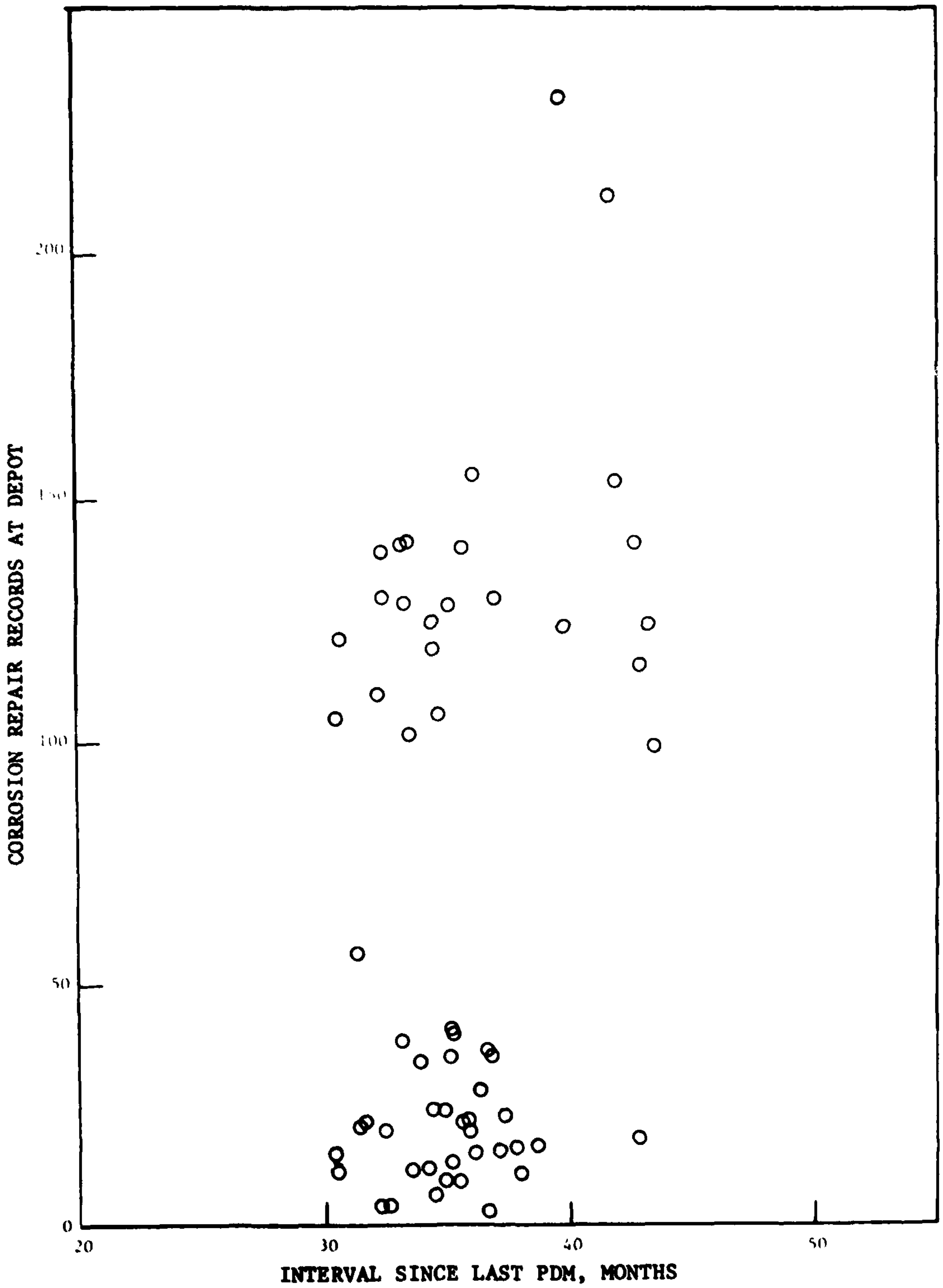

FIGURE 32. C-141A CORROSION REPAIR RECORDS AT DEPOT VS. PDM INTERVAL, FY 72.

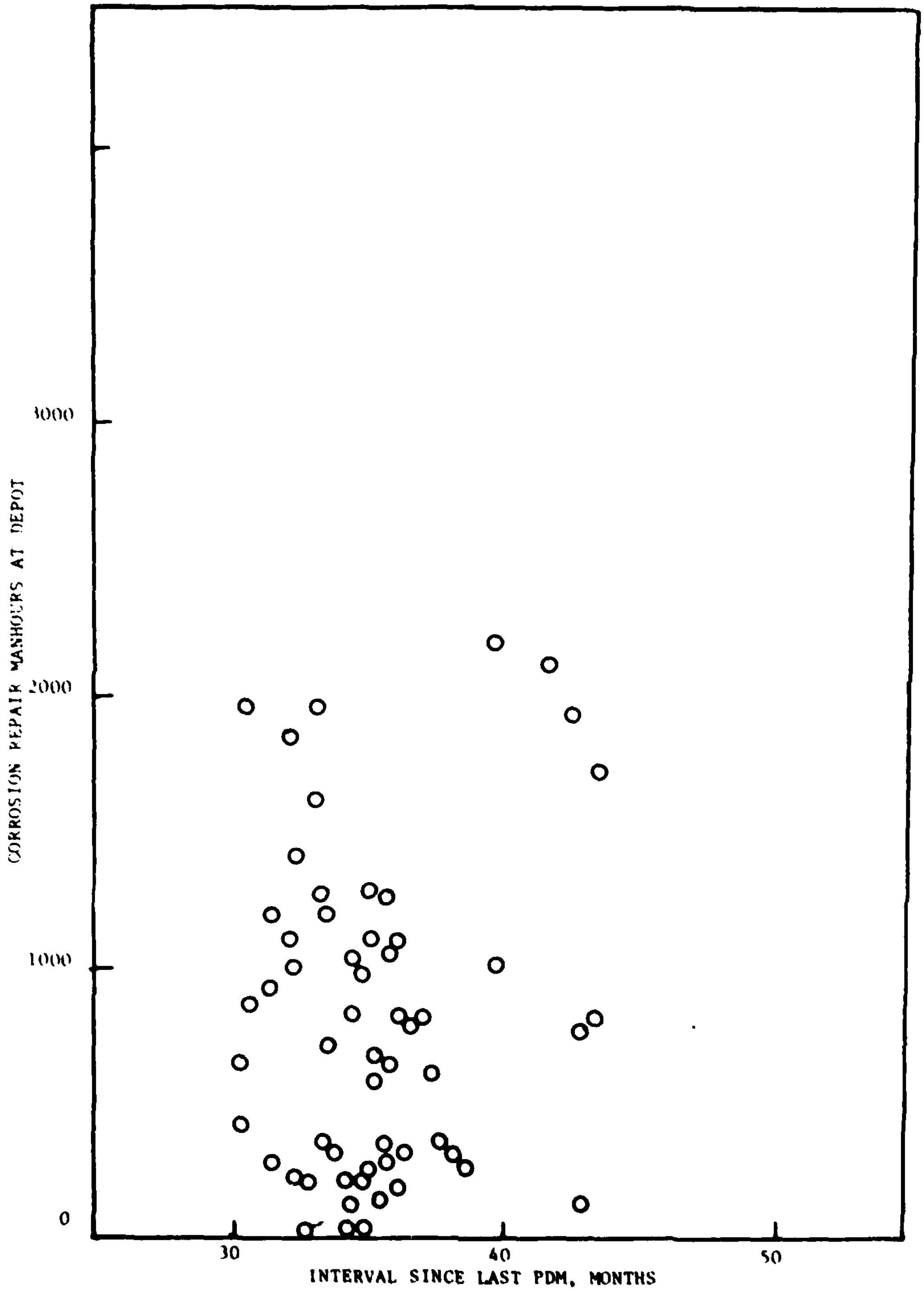

Figure 33. Corrosion repair manhours at depot maintenance, FY 72, vs. PDM interval. ACI information not available.

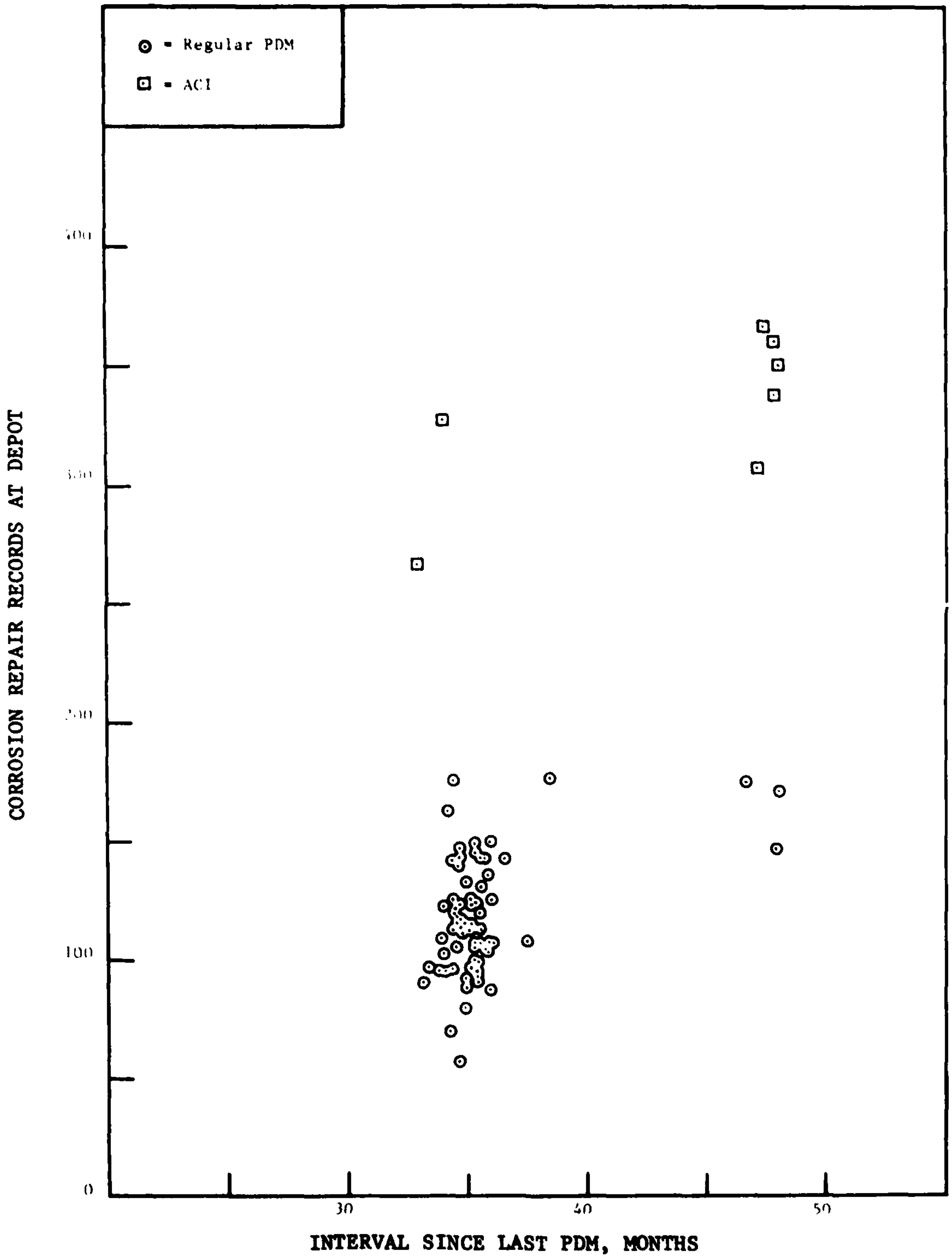

FIGURE 34. C-141A CORROSION MAINTENANCE RECORDS AT DEPOT VS. PDM INTERVAL, FY73.

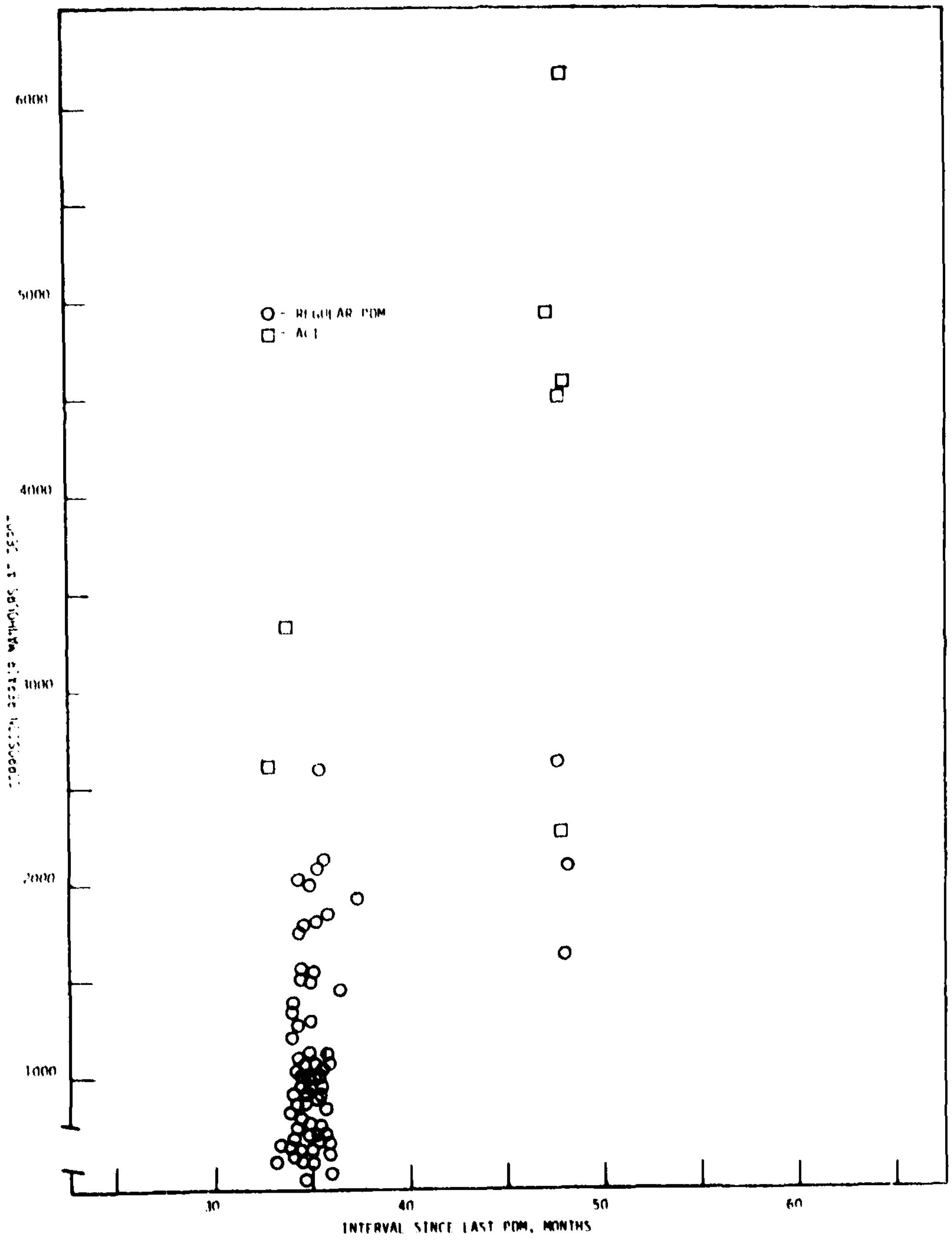

FIGURE 35. C-141A CORROSION REPAIR MANHOURS AT DEPOT VS. PDM INTERVAL, FY73.

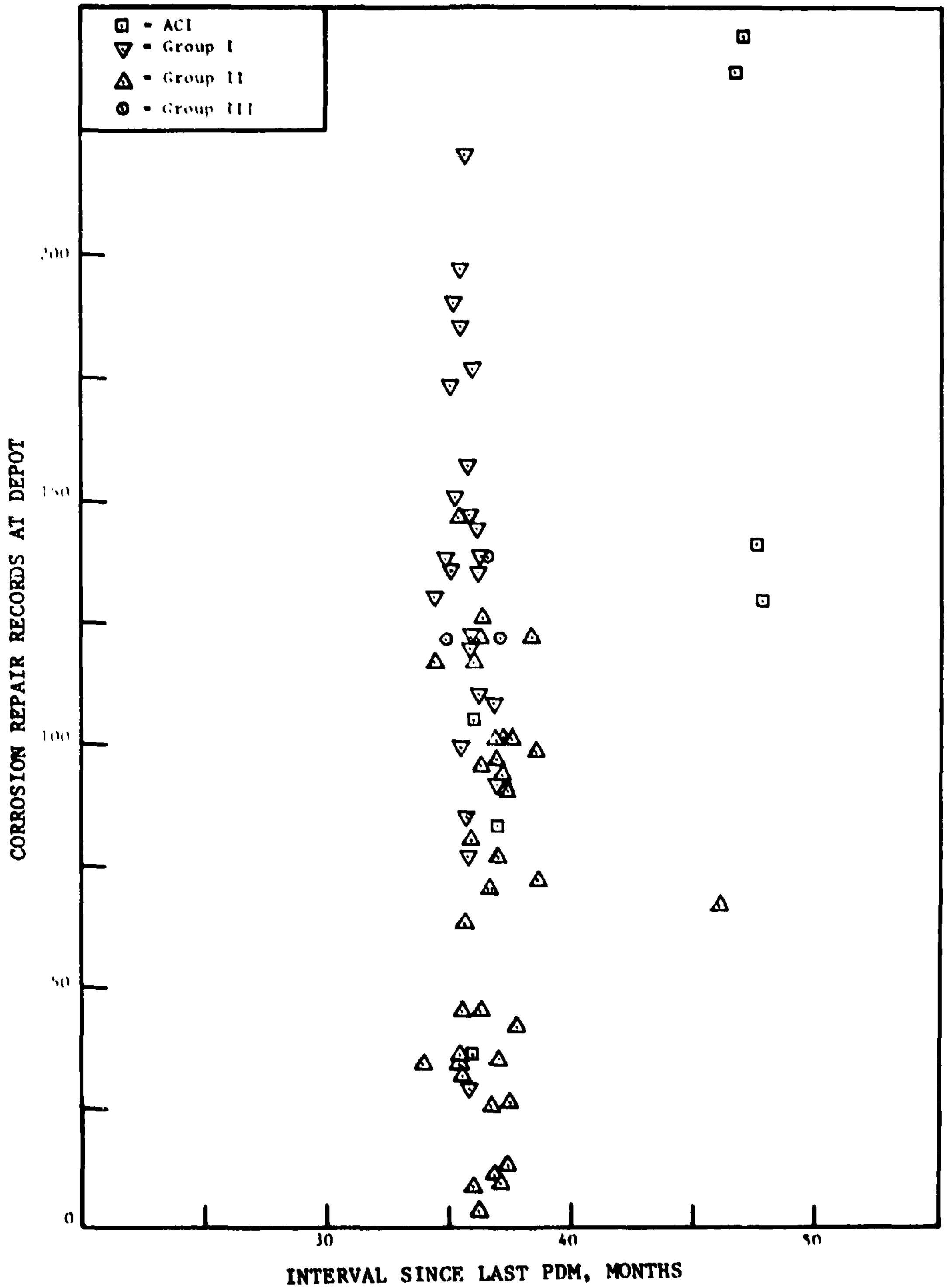

FIGURE 36. C-141A CORROSION MAINTENANCE RECORDS AT DEPOT VS. PDM INTERVAL, FY74.

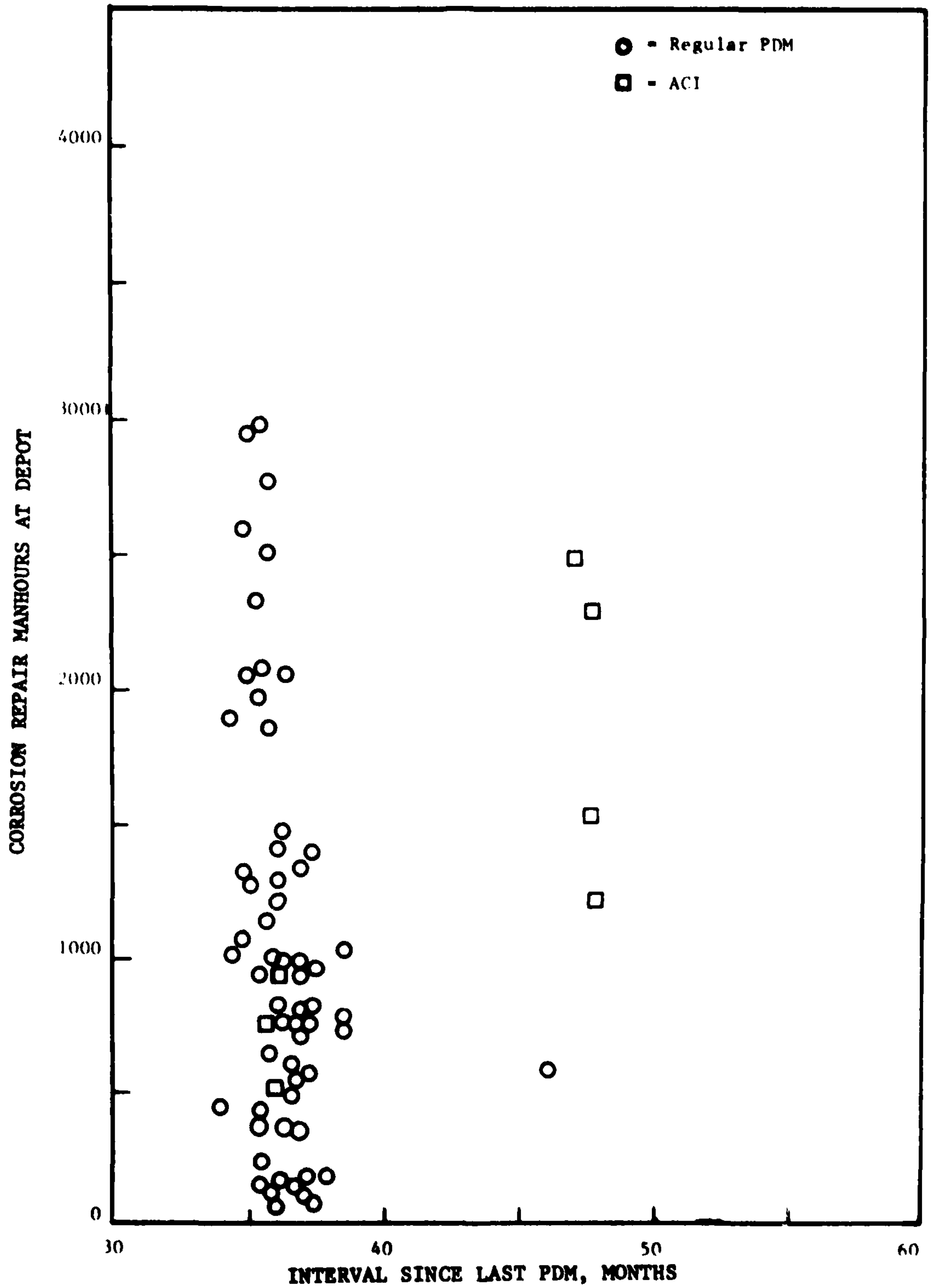

FIGURE 37. C-141A CORROSION MANHOURS AT DEPOT VS. PDM INTERVAL, FY74.

are identified, (which clearly reveals the error of interfacing the ACI and CIE programs.) In every case where a CIE aircraft has received an unusually high level of maintenance, it also has received the ACI package. Consequently, it is not possible to determine why these aircraft received more work from the AFM 66-1 records alone.

For FY 72 (Figures 32 and 33), one might develop an argument supporting a dependence of depot maintenance on PDM interval, but it would be weak. As noted above, data for this year is less detailed than that for the subsequent years. Two distinct groups of aircraft are apparent in Figure 32 (records), but they are not differentiated by manhours (Figure 33.) Although there is no information available to explain how these groups were different, it is probably the result of a change in documentation procedure at some point in the year.

In FY 73 (Figures 34 and 35), CIE aircraft are seen to have received considerably more maintenance than those on the normal interval. The four units with excessively high manhours also received the ACI "package" and all five ACI units had excessive records counts. The three CIE aircraft which received the regular "package", however, are well within the range of records and manhours for normal-interval units, albeit at the high end of that range. In addition, the fifth ACI unit is in the normal range of manhours.

A somewhat confusing situation occurred during FY 74 (although much less confusing than FY 75, which we do not discuss.) Part of this confusion is displayed in Figure 36 (records)

but the reader is spared the detail in terms of manhours (Figure 37). The situation is described (29) as follows:

> "FY 74 saw a more unstable year in the C-141 PDM program. The depot maintenance facility was using more man-hours than the AFLC/MRRB (Maintenance Requirements Review Board) had approved. This excess resulted in a study of the depot work cards in the DART (Daily Automatic Rescheduling Technique) data system. It was discovered that some job operations were being accomplished more than necessary. After the completion of this study, the approved number of man-hours showed a reduction from 13,171 man-hours to 11,273 man-hours. Any aircraft input after 27 Nov. 1973 would receive the reduced package. [Identified in Figure 36 are] the different groups of aircraft accomplished under each package; Group I being prior to Work Spec Rework, Group II after Rework, Group III consisting of three aircraft which were painted over and above a PDM, and the ACI aircraft. There is a substantial difference in ACI man-hours when the work was accomplished prior to Work Spec Rework."

Aircraft receiving the higher-manhour work-package are easily identified in Figure 37 as those above about 1600 manhours.

As we have noted previously, any group of aircraft exhibits a wide range of corrosion repair experience at depot. With so small a sample as the CIE or ACI groups - particularly when they are not truly representative of the population (cf. Tables 3, 4, 19, and 22) - one cannot draw reliable statistical inferences applicable to the entire force. It may be true that CIE aircraft have greater corrosion maintenance needs, but the records of maintenance actions at depot do not confirm it. In fact, the records would support extending the depot interval to 42 months, but probably not 48 months.

SECTION VIII

NORMALIZATION OF FIELD MAINTENANCE DATA TO A POSSESSION-QUARTER BASIS

The number of maintenance records or the manhours reported by an airbase over a given time interval represents the overall maintenance effort on all aircraft assigned to that base. (Transient aircraft maintenance is negligible.) Since the number of aircraft varies from base to base and from time to time, the data must be normalized before meaningful base-by-base comparisons can be made. Aircraft possession histories were available in the form of quarterly "C-141A Current Utilization Reports." These reports list for each aircraft, the serial number, the base of assignment, and some information relating to flight time and landings. A calendar-year quarter is a useful time period for normalizing maintenance data, being neither so short as to be unwieldy nor so long as to smooth the data and thus obscure detail. The number of aircraft assigned to each airbase by quarter from 1970 to 1976 are collected in Table 21.

If the number of maintenance actions at an airbase in a given quarter is divided by the number of possessed aircraft, the result is an average of maintenance actions per aircraft. Maintenance manhours may be treated in the same way. If one is interested in averages over time intervals of several quarters, then one would divide the total records by the sum of the possessed aircraft for each quarter in the interval.

It is possible, then, to compare airbases with respect to the average maintenance effort per aircraft and, in particular, to compare different time intervals for the same airbase. The

TABLE 21. TOTAL NUMBER OF C-141A AIRCRAFT STATIONED TO EACH AIRBASE, BY QUARTER 4Q70-4Q76.

Calendar Year Quarter	McGuire	Dover	Travis	Norton	Charleston	Altus	McChord	Robins and Wright-Patterson
4Q70	53	22	56	36	35	20	37	22
1Q71	(55)	(20)	(56)	(36)	(36)	(20)	(40)	
2Q71	55	20	56	36	36	20	40	18
3Q71	57	23	59	39	40	18	40	5
4Q71	58	24	58	39	40	17	40	5
1Q72	60	21	39	58	40	18	40	5
2Q72	58	21	41	58	40	18	40	5
3Q72	59	21	41	58	40	18	40	4
4Q72	59	21	41	58	40	18	40	4
1Q73	59	21	40	58	40	18	40	
2Q73	58	21	40	59	40	18	40	
3Q73	59	-0-	40	59	60	18	40	
4Q73	59		40	59	60	18	40	
1Q74	59		40	59	60	18	40	
2Q74	59		40	59	60	18	40	
3Q74	59		39	58	61	18	41	
4Q74	59		40	59	59	18	40	
1Q75	60		40	59	59	18	39	
2Q75	59		40	59	59	18	39	
3Q75	59		40	59	59	18	39	
4Q75	59		40	59	59	18	39	
1Q76	59		40	59	59	18	39	
2Q76	59		40	59	59	18	39	
3Q76	57		40	59	59	18	39	
4Q76	57		40	59	59	18	39	

Note: Data were not availabe for 1Q71. Values were assumed to be same as for quarter immediately following.

time dependence of the maintenance effort will be an important part of the basis for predicting future maintenance activity. Averages obtained by possession-quarter normalizing, however, will mask certain features of the data, notably:

--differences from one aircraft to another on the same base, such differences perhaps resulting from different missions, etc.,

--changes in maintenance effort (or reporting) over time intervals shorter than the period used to normalize the data.

Although the service environment is not homogeneous over the entire C-141A Force, it is reasonably homogeneous for the aircraft assigned to a single airbase. A possible exception might be the "dedicated" aircraft--see Appendix II page 11--but these are too few in number to be significant. One must look elsewhere to find explanations for intrabase variations of corrosion maintenance. Changes in maintenance effort as revealed in the AFM 66-1 records do occur over fairly short time intervals.

Maintenance data for the C-141A Force were provided in two parts covering the time intervals 4Q70 to 4Q74 and 1Q75 to 4Q76. The first part was to be analyzed for developing a predictive model, and the second part for testing the predictive model. Accordingly the possession-quarter data for those two time periods would be useful for normalizing the two sets of maintenance data. Total-maintenance records or total-maintenance manhours for a particular base divided by possession quarters for that base will yield the normalized numbers "average maintenance actions per aircraft per quarter" and "average maintenance manhours per aircraft

per quarter." Thus one obtains an index with which to compare the level of effort from one base to another. Such comparisons may be made not only on overall aircraft maintenance but also on numerous categories obtained by selective sorting of the AFM 66-1 data according to How-Malfunction, Work-Unit Code, etc. The possession-quarter data for the C-141A Force over the two time intervals are listed in Table 22.

An alternative to base-by-base comparisons would be to compare the percent of possession quarters with the percent of various categories of maintenance. The percent of possession quarters represents that part of the C-141A Force for which an airbase is responsible for maintenance. This may be compared with the percent of maintenance manhours, in order to determine if that airbase is doing more or less than its share of responsibility. These possession-quarter percentages also are listed in Table 22.

Such a comparison is shown in Tables 23, and 24, where the percents of total records and manhours are listed. The share of Travis AFB, in both actions and manhours, is significantly larger than its share of responsibility. One might conclude that the corrosion-maintenance effort at Travis is more aggressive compared with other bases.

There are problems with the data, however, which throw the percentage-type comparisons into question. The two most visible problems are the "McChord Anomaly" of the first data set, and the "Norton Anomaly" of the second. Because of these, the totals, and hence the percent for each base, are distorted. This will result whenever one airbase contributes

TABLE 22. C-141A AIRCRAFT POSSESSION-QUARTER DATA USED TO NORMALIZE FIELD MAINTENANCE REPAIR RECORDS

Airbase	Aircraft Possession Quarters 4Q70-4Q74	Percent	1Q75-4Q76	Percent
McGuire	985	21.2	440	20.7
Dover	235	5.1		
Travis	766	16.4	320	15.0
Norton	888	19.1	472	22.2
Charleston	787	16.9	464	21.8
Altus	311	6.7	136	6.4
McChord	678	14.6	296	13.9
Total	4,650		2,128	

Notes:
1. Numbers for each time interval are the sums of the respective numbers of Table 21. In the later time period, however, records of eight aircraft were not included, hence the numbers do not agree exactly with the sums from Table
2. In calculating percentages for the earlier time period, aircraft stationed at Robins and Wright-Patterson are not included.
3. Aircraft stationed briefly at Robins for PDM are considered to be assigned still at the original base.

TABLE 23. COMPARISON OF PERCENT POSSESSION QUARTERS WITH PERCENTS OF CORROSION MAINTENANCE ACTIONS (ORGANIZATIONAL LEVEL) MANHOURS FOR C-141A FORCE, BY AIRBASE, 4Q70-4Q74.

	Percent Possession Quarters	Percent Corrosion Maintenance Actions	Percent Corrosion Maintenance Manhours
McGuire	21.2	15.6	18.1
Dover	5.1	5.5	5.0
Travis	16.4	16.8	21.8
Norton	19.1	17.3	15.5
Charleston	16.9	18.3	18.5
Altus	6.7	5.1	6.5
McChord	14.6	21.3	14.4

TABLE 24. COMPARISON OF PERCENT POSSESSION-QUARTERS WITH PERCENTS OF CORROSION MAINTENANCE ACTIONS AND MANHOURS FOR C-141A FORCE, BY AIRBASE, 1Q75-4Q76.

	Percent Possession-Quarters	Percent Corrosion Maintenance Actions	Percent Corrosion Maintenance Manhours
McGuire	20.7	18.9	20.0
Travis	15.0	24.6	23.6
Norton	22.2	8.4	8.4
Charleston	21.8	33.5	30.4
Altus	6.4	4.5	5.2
McChord	13.9	10.1	12.5

an abnormally high or abnormally low input to the maintenance record system. The Norton Anomaly has the effect of inflating Travis's share (as well as every other airbase) of the field maintenance. Hence, comparing percent of force totals with percent of possession quarters does not yield reliable information. The possession-quarter normalized data are much more useful.

The gross (or total) corrosion maintenance data for the several airbases are shown, normalized to a per-aircraft per-quarter basis, in Table 25. Data from the two time periods are in good agreement, both for maintenance actions and manhours, for McGuire, Travis, and Charleston AFB's. The McChord and Norton Anomalies again are readily apparent. In the case of the Norton Anomaly, the fact that the manhours-per-record value is the same for both time periods supports the conclusion that data have been lost. The McChord Anomaly is discussed elsewhere, as well as the substantial change for Altus AFB.

Nearly-linear rates of field maintenance at each airbase were discovered quite early in this study. From these, field-maintenance rates data were calculated which could be used to predict maintenance. It is interesting to compare these predictions with the actual data for 1975-76. The predicted values, computed from the data of Table 9, p. 23, of the Interim Report (20 May 1976) also are listed in Table 25. Excellent agreement is observed for McGuire and Charleston AFB's, and the predicted values for Travis AFB are quite good. In the case of Altus and McChord AFB's the predicted values are a little

TABLE 25. GROSS C-141A CORROSION MAINTENANCE DATA NORMALIZED TO PER AIRCRAFT PER QUARTER BASIS. VALUES IN PARENTHESES FOR THE SECOND PERIOD ARE PREDICTED*.

	4Q70 - 4Q74			1Q75 - 4Q76		
	Records per Aircraft per Quarter	Manhours per Aircraft per Quarter	Manhours per Record	Records per Aircraft per Quarter	Manhours per Aircraft per Quarter	Manhours per Record
McGuire	30.0	87.7	2.9	28.5 (24.0)	76.1 (79.5)	2.7 (3.3)
Dover	42.5	98.5	2.3	-----------	------------	---------
Travis	40.8	133.0	3.3	51.0 (33.6)	124.0 (101.4)	2.4 (3.0)
Norton	37.4	84.4	2.3	11.8 (26.7)	29.7 (58.8)	2.5 (2.2)
Charleston	44.3	113.2	2.6	48.0 (42.9)	110.0 (105.6)	2.3 (2.5)
Altus	30.9	98.8	3.2	22.1 (26.1)	63.7 (84.3)	2.9 (3.2)
McChord	59.2	101.2	1.7	22.6 (33.6)	70.8 (52.8)	3.1 (1.6)
Robins**			12.1			5.3

* Table 9, p. 23, Interim Report, 20 May 1976.

** Nearly all records from Robins AFB are depot-level maintenance. Average manhours per record are included for comparison.

wide of the mark, but the correct change of direction was forecast. In the case of the Norton Anomaly, we suspect that the predicted values may be more reliable than that obtained directly from the records.

SECTION IX

MAINTENANCE DATA NORMALIZED TO POSSESSION-QUARTER BASIS

The corrosion-maintenance data normalized to a possession-quarter basis are presented in Tables 26 through 29 by airbase. These tables represent a breakdown of the corrosion-maintenance information according to How-Malfunction code, When-Discovered code, Action-Taken code, and Work-Unit Code, respectively. In Tables 26, 27 and 28 there are two columns of entries for the two time periods. For each category there are two entries, the upper one is mean manhours per aircraft per quarter, MH/AC/Q, for that time period, airbase, and How-Malfunction code, etc. The data had been tabulated originally for maintenance records per aircraft per quarter as well, but to avoid presenting too many tables, these have not been reproduced. Instead we have entered in Tables 26 through 28 the ratio of mean manhours per aircraft per quarter to the mean records per aircraft per quarter. This is the lower entry, identified as manhours per corrosion record. Manhours per record data are not included in Table 29 because it would be too confusing. In all these tables, absence of an entry does not mean that the value is zero. Values of less than one have not been included in order to reduce the volume of data presented.

The largest manhours entry for all airbases and both time periods in Table 26 is the How-Malfunctioned code 190, Cracked. For most bases, except Altus, Norton and McChord, the second largest is How-Malfunction code 846, Delaminated, followed in third place by code 170, Corrosion--Mild to Moderate. For both Norton and McChord, Corroded--Mild to Moderate is the

TABLE 26. DISTRIBUTION OF C-141A CORROSION MAINTENANCE MANHOURS AMONG HOW MALFUNCTION CODES, BY AIRBASE.

	McGuire		Travis		Norton		Charleston		Altus		McChord	
	I	II	I	II	I	II	I	II	I	II	I	II
230 Dirty	6.2 1.4	6.9 1.1	13.3 1.4	12.6 1.2	12.0 1.8	2.4 1.4	8.9 1.9	8.3 1.6	7.1 2.6	3.4 2.1	6.6 2.1	4.9 1.8
190 Cracked	45.8 3.1	34.0 3.1	60.7 3.5	47.3 2.8	42.1 2.4	11.9 2.8	48.9 2.9	39.9 2.5	41.2 3.1	26.4 3.3	36.5 2.4	32.4 3.9
846 Delaminated	24.4 4.1	26.9 3.5	39.4 5.4	35.2 3.4	20.2 2.7	8.5 2.9	35.4 3.3	37.3 2.9	20.9 3.8	25.3 3.2	20.9 1.4	21.1 4.1
170 Corroded Mild to Moderate	5.3 1.4	1.9 1.3	16.5 2.7	19.6 2.0	7.9 4.4	4.0 1.9	13.1 1.8	13.8 1.8	11.1 1.5	5.4 1.5	33.6 1.0	7.1 1.5
117 Deteriorated	7.0 4.2	3.9 2.6	7.9 4.9	4.8 3.0	2.5	2.4 4.0	5.0 2.5	4.3 2.0	1.8		6.6 2.9	2.0 2.5
865 Coating, Sealant							4.1 1.1	3.9 1.3	22.1 5.9			
667 Corroded, Severe	1.3		1.1	2.1	1.7		1.0	1.8				1.1
Total Manhours	90.0	73.6	138.9	121.6	86.4	29.2	116.4	109.3	104.2	60.5	104.2	68.6
Mean Manhours (TABLE 18)	94.1	82.8	138.2	124.0	87.1	30.4	123.5	107.5	-	-	98.8	69.3

Notes: 1. Time period I is 4Q70 to 4Q74, and period II is 1Q75 to 4Q76, inclusive.
2. Upper entry in each block is mean manhours per aircraft per quarter, and lower entry is manhours
3. Absence of manhours entry indicates number is less than one.

TABLE 27. DISTRIBUTION OF C-141A CORROSION MAINTENANCE MANHOURS AMONG WHEN DISCOVERED CODES, BY AIRBASE.

When Discovered	McGuire		Travis		Norton		Charleston		Altus		McChord	
	I	II	I	II	I	II	I	II	I	II	I	II
M Major Inspection	22.3 2.1	15.4 1.4	25.3 1.6	33.3 1.5	28.0 1.9	8.9 2.1	22.6 1.5	20.9 1.2	26.7 2.4	24.4 2.2	32.3 1.3	23.7 2.8
K Minor Inspection	14.2 1.7	4.5 1.2	18.2 1.4	8.0 1.0	24.7 1.6	2.5 1.3	23.7 1.6	12.0 1.3	20.5 2.2	3.6 1.7	31.1 1.3	5.9 1.4
F Between Flights, Ground Crew	42.0 5.3	43.5 4.8	51.5 7.4	42.9 4.2	23.5 6.5	10.5 3.5	39.7 5.4	44.0 4.4	37.4 5.7	26.6 5.2	23.9 5.3	28.8 6.1
S Depot Level Maintenance	7.4 2.3	3.0 2.1	21.6 4.7	14.9 2.4	8.2 2.1	3.0 2.1	12.4 2.5	8.3 1.0	9.7 2.5	4.8 2.0	13.7 2.1	5.6 2.7
J Preflight Inspection	2.7	4.5 3.5	17.0 11.3	11.9 6.6		2.0	8.6 6.8	5.9 5.4	5.4			2.2
D In-flight No Abort	0.9	1.1	3.9	1.7	1.4		2.1	3.9 3.0	1.4	1.8	1.1	1.7
Q Special Inspection				8.2 8.2		1.1	5.5	10.9 4.2				

Notes:
1. Time period I is 4Q70 to 4Q74 and period II is 1Q75 to 4Q76, inclusive.
2. Upper entry in each block, is mean manhours per aircraft per quarter, and lower entry is manhours per record.
3. Absence of manhours entry indicates number is less than one.

TABLE 28. DISTRIBUTION OF C-141A CORROSION MAINTENANCE MANHOURS AMONG ACTION TAKEN CODES, BY AIRBASE.

Action Taken	McGuire I	McGuire II	Travis I	Travis II	Norton I	Norton II	Charleston I	Charleston II	Altus I	Altus II	McChord I	McChord II
V Clean	5.8 1.7	8.1 1.2	14.7 1.5	13.3 1.3	11.7 1.8	2.4 1.5	8.8 2.0	8.6 1.6	5.4 2.4	3.7 2.3	4.2 2.2	5.1 2.3
G Repair and/ or Repl.	31.7 2.9	33.4 2.6	61.1 2.8	52.6 2.3	24.7 1.9	10.2 2.3	60.4 2.2	57.0 2.1	21.9 5.7	28.1 3.1	47.4 2.0	39.6 3.1
R Remove and Replace	20.3 4.7	22.0 4.3	50.7 9.1	29.2 5.8	13.5 6.5	5.6 4.7	27.7 5.6	20.6 4.9	21.6 6.3	10.4 4.5	9.7 5.1	14.1 8.3
Z Corrosion (Repair)	4.5 1.3	1.4 1.2	5.3 1.2	17.0 1.9	7.2 1.2	3.9 1.9	11.4 1.7	12.3 1.7	10.9 1.5	5.0 1.5	31.4 1.0	6.3 1.4
F Repair	18.2 2.6	2.2			21.5	4.2 3.2			33.7 2.4	12.0 2.9		
P Removed	7.2 4.5	6.4 4.0	7.8 5.6	7.8 4.3	7.3 5.4	2.5 3.1	7.1 3.6	9.5 3.3	10.0 5.2	3.6 3.3	10.5 4.2	4.7 4.7

Notes: 1. Time period I is 4Q70 to 4Q74, and period II is 1Q75 to 4Q76, inclusive.

2. Upper entry in each block is mean manhours per aircraft per quarter, and lower entry is manhours per record.

3. Absence of manhours entry indicates number is less than one.

TABLE 29. DISTRIBUTION OF C-141A CORROSION MAINTENANCE MANHOURS AMONG SELECTED (MAJOR) WORK UNIT CODES, BY AIRBASE.

	McGuire		Travis		Norton		Charleston		Altus		McChord	
	I	II	I	II	I	II	I	II	I	II	I	II
11BA Cargo Ramp, General	4.8	3.9	4.6	3.6	4.9	1.6	5.1	2.5	2.7	2.0	5.8	3.3
BD Petal Door, General	5.6	3.4	5.3	4.0	3.9	2.5	7.1	4.1	2.8	3.9	5.0	2.5
BK Pressure Door, General	1.5	2.1	3.8	2.7	1.0			1.3			1.7	
11CB Cargo Compartment Troop Door		1.7	3.0	2.2								
11EA Main Landing Gear, Outboard Door	2.5	2.4	5.0	4.7	2.0	1.9	5.2	4.6	5.4	3.7	3.0	2.0
EB Main Landing Gear, Inboard Door	1.2	1.6	1.7	2.1				1.1	1.1			
EE Aft Nose Landing Gear Door	1.7	1.7	3.9	2.8	1.1		5.7	3.9	9.4	1.9		1.1
11FA Forward Fuselage, Nose to F.S. 451	4.8	2.8	10.0	4.7	5.8	1.3	6.0	7.2	3.4	1.4	8.0	3.3
FB Forward Fuselage, F.S. 451-735	5.3	3.2	6.3	9.0	3.7	1.1	11.0	13.5	1.6	1.1	6.6	3.0
FC Center Fuselage, F.S. 735-1058	3.0	1.1	3.5	3.9	3.4		3.1	2.8	2.6	2.5	2.7	
FD Aft Fuselage, F.S. 1058-1855	7.0	3.8	8.4	7.8	8.4	2.2	5.6	5.5	2.7	1.3	6.1	3.7
FE Wheel Well Pod	7.3	4.1	7.0	5.3	7.8	2.0	8.7	10.6	6.7	3.8	5.4	3.5
11GA Center Wing-Box Beam	1.6	1.6	3.1	5.7	1.8		2.8	8.6	1.8	2.8	3.3	9.2
GB Inboard Wing	2.5	4.9	5.4	10.2	2.4		5.1	6.0	2.2	4.5	3.6	5.9
GC Outboard Wing	3.4	3.9	6.5	6.2	2.2	1.1	6.1	5.0	2.7	3.3	4.2	4.1
11GE Pylons	2.4	2.3	14.1	3.0	2.6	1.1	3.0	2.0	2.3	2.8	3.1	2.0
14AA Aileron Control System	3.6	1.4	2.9	2.[illegible]	2.0		1.8		2.0	2.0	2.5	1.2
14GA Wing Flap Assembly	5.6	7.2	5.6	6.4	7.5	1.8	6.3	4.6	8.4	5.3	9.0	6.1
GB Wing Flap-Mechanical	2.0						3.1				2.3	
14HD Wing Spoiler-Mechanical	1.2		3.5	1.6	1.0		2.3	1.7		1.5		
46AA Fuel Tank-General								1.9	22.0			

Notes: 1. Time period I is 4Q70 to 4Q74, and period II is 1Q75 to 4Q76, inclusive.

2. Entries are mean manhours per aircraft per quarter. Absence of entry means value is less than one.

second-largest entry. The second largest entry for Altus is code 865 coating, sealant, etc. (which correlates with the Altus Anomaly.) At all bases How-Mal code 117, Deteriorated and 667, Corroded severe are relatively unimportant. Code 865, Coating Sealant etc. is of minor importance at all bases except for Altus and Charleston.

The three anomalies are apparent in Table 26. The McChord Anomaly appears as the wide difference between the two time periods for How-Malfunction code 170, Corroded--Mild to Moderate. In the first time period, McChord reported nearly 44 manhours per aircraft per quarter (MH/AC/Q), but in the second time period only 7.1 MH/AC/Q. McChord shows a sharp decline for no other How-Mal codes. The Norton Anomaly appears as a sharp decrease for every How-Malfunction code except code 117, Deteriorated. The Altus Anomaly is the remarkably large value of 22.1 MH/AC/Q reported for the first time period for How-Malfunction code 865, coating and sealant. When studying Tables 26, 27, and 28, one must remember the presence of these three anomalies.

A number of comparisons may be made between the data for the several bases where there are no apparent anomalies. Consider How-Mal code 190, Cracked, which is seen to be the most used code. We notice that the value ranges from 37 to nearly 61 MH/AC/Q, a variation of not quite double over the six airbases. In the first time period there is a factor of two between the lowest and the highest value for code 230, Dirty, ranging from 6.2 to over 13 MH/AC/Q. Code 846 varies by a factor of two from 20 to 39; and 117 Deteriorated varies from less than 2 to nearly 8 MH/AC/Q. If the McChord anomaly

is ignored for the first time period, it may be noted that code 170, Corroded--Mild to Moderate, varies from 5 to nearly 17 MH/AC/Q, or by a factor of three. Travis AFB is the highest always, except for the McChord Aromaly.

The airbase reporting the lowest manhours is not the same for each of the How-Malfunction codes, however. The honor of reporting the lowest MH/AC/Q in the first time period wanders from one airbase to another, except that Charleston AFB never wins (or loses, as the case may be). At the bottom of Table 26 are listed the totals for each column obtained by summing the entries. Below that are listed the corresponding mean values from Table 18. Values from these two sources are in good agreement with one another. It should be remembered that these numbers were obtained by different methods. The data listed in Table 18 were obtained from visual interpretation of Figures 17 and 18, which were prepared from the data of aircraft assigned continuously to the airbases in question. These are subsets of the aircraft from each base. In addition, all maintenance records in the corrosion data file are included. The data of Table 26, however, represent all aircraft that were assigned to a particular airbase, but only selected How-Malfunction codes are included. In view of these differences, the good agreement in result lends a measure of confidence to the methods of analysis.

The differences from one airbase to another in the use of How-Malfunction codes are significantly large, and this supports conclusions drawn from Figures 17 and 18. From Table 26 one

would conclude that the average aircraft at Travis AFB receives over three times as many corrosion maintenance manhours as the average aircraft based at McGuire AFB, and twice as many as that at Norton AFB. One would like to trace these variations to environmental differences at each airbase and conclude that the environment of Travis AFB is twice as severe as that of Norton and three times as severe as that of McGuire. These ratios, however, are not the same for other categories of degradation. Travis aircraft get dirty, for example, the same rate as those at Norton, but twice as fast as at McGuire.

It is interesting to compare the two time periods to see whether the patterns are the same in 1975-76 as they were in 1970-74. From code 230 Dirty, aircraft seem to have been as dirty in the second time period as in the first at McGuire, Travis, Charlestom, and McChord AFB's. Altus aircraft, however, seem to have been only half as dirty in the second time period as in the first. Norton AFB must be neglected in comparing the two time periods because of the anomalous decrease in its record-maintenance rate. Code 190, Cracked shows a sharp decrease in maintenance-manhours at all bases except McChord. Delaminations are constant, but corrosion problems decline sharply at McGuire and Altus AFB, remaining about the same at Travis, Norton, and Charleston AFB's. In this instance, one must ignore McChord because of its anomaly. Deterioration, code 117, declined sharply at McGuire, McChord, and Travis, but remained about the same level at Norton, and Charleston. Code 667 Corroded severe, is unremarkable in both time periods at all bases.

Code 865, Coating, Sealant, reveals the Altus anomaly, where an excessively large value of 22.1 MH/AC/Q falls to less than one.

The distribution of corrosion-maintenance manhours among When-Discovered codes is listed in Table 27. For most airbases, the largest part of maintenance manhours are expended for actions discovered during major inspections, minor inspections, or inspection between flights by the ground crew. The notable exceptions are Travis, which has substantial maintenance manhours expended for discrepancies discovered in depot-level maintenance and returned for action at the base, and in pre-flight inspections. Charleston AFB as well, shows fairly high values for these two categories and McChord shows a fair amount for depot-level inspections. It is interesting that in many cases the largest number of maintenance manhours are expended in repairing discrepancies discovered between flights by the ground crew. This probably results because there are more of these inspections than the others.

The data of Table 29 is a briar patch of confusion which defies rational analysis. With patience, however, one can discern some interesting features. Consider the first time period, and only those entries where the MH/AC/Q value exceeds five. The top line, 11BA, Cargo Ramp General, shows two entries larger than five for Charleston and McChord AFB's. The values for McGuire, Travis, and Norton--though not exceeding five--are nevertheless comparable with the values for Charleston and McChord. The value for Altus AFB, however,

is only about half the largest value for that particular work-unit-code. This is a pattern that occurs several times in the work-unit-code distribution, for example, 11BD, 11FA, 11FD, 11GB, and 11GE. In some of these cases the pattern is not identical to that described for 11BA, differing in that the values for other bases are approximately the same as at Altus, e.g., 11GB and 11GE. Sometimes the values for the other bases contain one entry which is excessively large compared with all entries for that particular base, e.g., 11FA, 11FB, and 11GE.

There are three work-unit code classifications for which Altus AFB has the largest number among all the six airbases. These codes are 11EA, main landing gear outboard door, 11EE, aft nose landing gear door, and 45AA fuel tank general. It is easy to rationalize the larger values for the first two work-unit codes as being correlated with the training mission profile at Altus AFB, since landing gears get more use there than at other bases. This is supported by the fact that the use of work unit codes 11FE wheel-well pod, and 11GA, wing-flap assembly, also are large at Altus AFB. Similarly, since training missions would involve relatively light use of the cargo ramp and petal doors, one might expect to find low values for corrosion maintenance of these areas. This surmise is borne out by the previously mentioned low values for codes 11BA, and 11BB. Altus AFB also shows a curiously low maintenance frequency for those regions of the aircraft which are exposed to the outside weather, such as 11FA, and 11FB forward fuselage, 11FC, center fuselage, 11FD, aft fuselage

11GB, inboard wing, and 11GC, outboard wing. This low maintenance rate seems to correlate with observations during an inspection of 17 of the 18 aircraft based at Altus AFB (Appendix II).

The large value of 22 MH/AC/Q for Work-Unit-Code 46AA, fuel tank general, again portrays the Altus Anomaly. This value corresponds almost exactly with the value of 22.1 MH/AC/Q for How-Malfunction code 865, coating and sealant, and suggests a strong correlation between the two codes. Certain work-unit codes are problem areas at every airbase; for example, 11FE repairs to wheel-well pod, and 14GA wing-flap assembly, require more than five MH/AC/Q. Similarly, corrosion maintenance exceeds five MH/AC/Q at most airbases for work-unit codes 11BD, petal-door general, 11FA, and 11FB, forward fuselage, and 11FD aft fuselage. The inference that these areas are corrosion-prone agrees with the condition of aircraft observed in the field (Appendix II).

Travis AFB shows unusually high maintenance rates in the two work-unit codes, 11FA, forward fuselage, nose to FS 451, and 11GE, pylons. Similarly Charleston shows an unusually high repair rate for 11FB, forward fuselage, FS 451-735. There seems to be no obvious explanation for these large values, particularly as they are not uniform from one base to another. We see no reason why the nose region, 11FA nose to F.S. 451 should be unusually high in corrosion at Travis, whereas the section immediately following, 11FB forward fuselage F.S. 451-735 should be unusually high in corrosion maintenance at Charleston. It is possible that some bases might systematically

record corrosion maintenance under preferred work-unit codes, that is, lump maintenance records into one category. But this is not apparent from the data base itself.

For the period 4Q70 - 4Q74 we have prepared a comparison of these six airbases with respect to groups of How-Malfunction codes with the When-Discovered code, i.e., the type of inspection when the discrepancy was discovered. The results are shown in Tables 30A-30H. Groups of work-unit codes were formed by combining those of a similar nature. For example, Group 1 contains doors, hydraulic, Work-Unit codes 11BA through 11BM; Group 2 contains doors mechanical by Work-Unit codes 11CA through 11CC; etc. These tables list the average repair records per aircraft per quarter, rather than manhours per aircraft per quarter, and hence correspond to the discrepancy-discovery rate instead of the cost-of-repairs rate. We show only four categories of When-Discovered code, that is, major inspection, minor inspection, between-flights by ground-crew inspection, and depot-level inspection.

Average values and standard deviations for the six airbases were computed for each type of inspection. We have noted in Tables 30A through 30H those entries which are either unusually high or unusually low compared with the averages, indicating them with the letter H or L respectively. Upon examining only these high and low values, a number of observations may be made.

Consider McGuire AFB. In every group of Work-Unit codes but two, (Group 3, doors electrical; and Group 8, fuel system).

TABLES 30A - 30H. AVERAGE REPAIR RECORDS PER C-141A AIRCRAFT PER QUARTER FOR SELECTED REPAIR AREAS, COMPARING TYPE INSPECTION (WHEN DISCOVERED) WITH AIRBASE, 4Q70 to 4Q74.

TABLE A. GROUP 1: DOORS, HYDRAULIC, WORK UNIT CODES 11BA to 11BM.

AIRBASE

Type Maintenance	McGuire	Travis	Norton	Charleston	Altus	McChord
M Major	.89	1.1	1.8	1.3	.96	3.3(H)
K Minor	.74	1.0	2.0	1.3	1.0	3.4(H)
F Between Flights	1.5(H)	.92	.58	1.1	0.50	.81
S Depot	.30	.20(L)	.45	.41	0.20(L)	.58(H)

TABLE B. GROUP 2: DOORS MECHANICAL, WORK UNIT CODES 11CA to 11CC.

Type Maintenance	McGuire	Travis	Norton	Charleston	Altus	McChord
M Major	.14	.15	.10	.17	.11	.72(H)
K Minor	.10	.16	.15	.18	.08	.76(H)
F Between Flights	.30(H)	.31(H)	.12	.21	.18	.13
S Depot	.03	.02	.04	.05	.06	.13(H)

TABLE C. GROUP 3. DOORS ELECTRICAL, APU, DOORS LANDING GEAR, WORK UNIT CODES 11D, 11E.

Type Maintenance	McGuire	Travis	Norton	Charleston	Altus	McChord
M Major	.71	.84	.86	.91	.99	1.4(H)
K Minor	.58(L)	.76	1.0	.97	.99	1.3(H)
F Between Flights	.69	.90	.21(L)	1.3	1.7(H)	.37
S Depot	.16(L)	.15(L)	.26	.32	.40	.37

TABLES 30A - 30H Con't.

TABLE D. GROUP 4: FUSELAGE, WORK UNIT CODES 11FA to 11FE.

Type Maintenance	McGuire	Travis	Norton	Charleston	Altus	McChord
M Major	3.5	4.3	5.0	4.1	2.4(L)	5.8(H)
K Minor	2.6	3.0	4.6	3.9	1.9(L)	4.9(H)
F Between Flights	1.9(H)	1.6	1.1	1.7	.73(L)	1.1
S Depot	1.2	1.1	1.3	1.6	1.0	1.9(H)

TABLE E. GROUP 5: WINGS AND PYLONS, WORK UNIT CODES 11GA to 11GG.

Type Maintenance	McGuire	Travis	Norton	Charleston	Altus	McChord
M Major	1.3	2.4	1.6	2.8	1.3	3.5(H)
K Minor	.79(L)	1.8	1.4	2.5	.92	3.0(H)
F Between Flights	.99(H)	.90	.55	.90	.56	.52
S Depot	.50	2.0(H)	.48	.91	.51	1.0

TABLE F. GROUP 6: FLIGHT CONTROLS EXCEPT EMPENNAGE, WORK UNIT CODES 14A, 14B, 14F to 14H.

Type Maintenance	McGuire	Travis	Norton	Charleston	Altus	McChord
M Major	2.2	2.7	2.9	3.3	2.8	4.9(H)
K Minor	1.7(L)	2.7	3.1	3.2	2.2	5.2(H)
F Between Flights	1.2(H)	.89	.45(L)	.98	0.9	.69
S Depot	.44	.36(L)	.71	.81	.8	1.2(H)

TABLES 30A - 30H Cont'd.

Table G. Group 7: EMPENNAGE FLIGHT CONTROLS, WORK UNIT CODES 14C to 14E.

Type Maintenance	McGuire	Travis	Norton	Charleston	Altus	McChord
M Major	.53	1.5(H)	1.1	.78	.42(L)	1.2
K Minor	.41	1.0	1.2(H)	.77	.31(L)	1.1
F Between Flights	.18(H)	.11	.07	.11	.10	.09
S Depot	.13(L)	.18	.24	.21	.18	.23

TABLE H. GROUP 8 FUEL SYSTEM, WORK WNIT CODES 46A to 46G.

M Major	.06	.05	.02	.14	1.0(H)	.11
K Minor	.03	.04	.03	.13	.97(H)	.13
F Between Flights	.12	.19	.12	.26	1.1(H)	.15
S Depot	.03	.01	.005	.06	.14(H)	.02

Note (H). A statistically high value, compared with mean for all bases, this type inspection.

Note (L). A statistically low value, compared with mean for all bases , this type inspection.

The discrepancy-discovery rate at major and minor inspections, on the other hand, is always below average, and in three cases, Group 3 doors electrical, Group 5 wings and pylons, and Group 6 flight controls, except enpennage, unusually below average. The discrepancy-discovery rate for depot-level inspection is below the six-base average or somewhat below average, but never significantly below average. It is significantly below average in Group 3, doors electrical, and Group 7, empennage flight controls.

This suggests that, for one reason or another, corrosion maintenance at McGuire AFB has been of relatively low priority at major and minor inspections in comparison with other maintenance efforts. Furthermore, discrepancies are being discovered at the between-flight by ground-crew inspections. From the fact that depot-level discrepancy-discovery rates are not unusually high, it would appear the corrosion maintenance at McGuire AFB is being effected, which is born out by the consistently low maintenance at depot on McGuire Aircraft (cf. Figure 31).

It would seem reasonable to assume that effective corrosion-control maintenance at major and minor inspections would minimize the discrepancy-discovery frequency at other inspections, such as between flights. The converse also may be true, namely, what is not found and corrected at major or minor inspection will result in a higher between-flight discrepancy-discovery rate. One might reasonably question whether it is not more efficient to discover and correct discrepancies during major and minor inspections as opposed to those done between flights. It is

also reasonable to question whether the cost of correcting discrepancies is higher or lower for the relative inspection.

It is also reasonable to draw the same assumptions concerning depot-level inspections. If discrepancies are discovered at major inspection, minor inspection, and between flights, i.e., at field-level inspection--then would one find a lower rate of discrepancy discoveries at depot-level inspections; and conversely, if field-level inspections were less effective and if repair of discrepancies were below average then might one expect to find depot-level discrepancy discoveries at a higher rate. The nature of repair records contained in Tables 30A through 30H, however, probably would prevent forming any such conclusion concerning depot-level-discovered records. The data in these tables represent field maintenance, and those discovered during depot-level maintenance represent those discrepancies which were not corrected at depot but were returned to the field for correction. As we have noted elsewhere, there is no uniform policy at depot concerning which discrepancy or the number of discrepancies that will be returned to the field for individual aircraft. Accordingly, the rate of discrepancy discoveries at depot-level inspection is not indicative of the quality or the condition of the aircraft at the time it is delivered to depot and no meaningful comparisons of aircraft condition can be based upon these numbers.

The data for McChord AFB are an interesting contrast with those of McGuire AFB. In every work-unit code group (except the anomalous fuel-system work-unit codes) the frequency of

discrepancy discoveries is average or significantly above average. On the other hand in a total of seven times at major and between-flight inspections it is always either average or below average. Interestingly, in almost every case where McChord AFB shows a significantly high discrepancy-discovery rate at major and minor inspections, it also shows a significantly high rate of discrepancy discoveries at depot-level inspection. The only exceptions are Group 3, electrical doors, and Group 5, wings and pylons. If we could be sure that the McChord Anomaly is not purely an artifact stemming from a high interest in reporting discrepancies (and the high rates for depot-level inspection suggest that this may indeed be the case), then one might take these values as evidence that McChord actually experienced a higher level of corrosion damage as discovered at major, minor, and depot-level inspections.

Altus AFB shows again a low maintenance rate on the fuselage as significantly low discrepancy-discovery rates in Table 30B, Group 4, fuselage. Low values are also noted at major and minor inspections in Table 30G, Group 7 empennage flight controls. We have speculated on the role of gypsum (calcium sulfate) content in the wash water at Altus AFB, and whether it might not act as a corrosion inhibitor. The personnel at Altus AFB are convinced (Appendix II) that the gypsum contributes to their corrosion problems, and one must admit that the present of the substance on the surface of the aircraft is unsightly. Nevertheless, low maintenance rates do suggest that some beneficial factor may be effective at Altus other than a milder or less-corrosive weather environment.

There are two notable exceptions to low rates at Altus, the first is a significantly high rate at between-flights inspections for Group 3, electrical doors, contrasted with low rates for hydraulic doors and mechanical doors, Groups 1 and 2. We offer no explanation for this difference between the three types of doors. The second exception is fuel system, the Altus Anomaly, Group 8, in which Altus shows significantly high discrepancy discovery rates at all inspections.

The distribution of C-141A corrosion maintenance records among How-Malfunctioned codes and Action-Taken codes for 4Q70 to 4Q74 is shown in Tables 31-36 for the six Airbases. The values in these tables are records per aircraft per quarter. The totals for each column would correspond to the entries in Table 26, and the sums for each row would correspond to the entries in Table 28. It should be noted that the entries in Tables 26 to 28 are manhours per aircraft per quarter, whereas those of Tables 31 to 36 are records per aircraft per quarter. The values of Tables 26 to 28 may be converted to those Tables 30 through 36 by dividing the first entry by the second entry in each box. Tables 26 to 28 include all Action-Taken codes or all How-Malfunction codes, respectively, and hence would be somewhat larger than the corresponding values of Tables 31 through 36. Tables 31 through 36 permit a comparison of the airbases according to how the discrepancies, identified by How-Malfunction, were corrected, according to Action. In Table 31, for example, the bulk of How Malfunction code 230, dirty received action "clean" at McGuire AFB--a little

TABLE 31. DISTRIBUTION OF C-141A CORROSION MAINTENANCE RECORDS AT McGUIRE AFB AMONG HOW-MALFUNCTION AND ACTION TAKEN CODES, 4Q70-4Q74. VALUES ARE RECORDS PER AIRCRAFT PER QUARTER.

	How Malfunctioned					
Action Taken	230 Dirty	190 Cracked	846 Delaminated	170 Corroded Mild	117 Deteriorated	865 Coating Sealant
V Cleaned	2.6					
G Repair/ Replace	0.1	6.7	2.2	0.1	0.9	0.1
R Remove & Replace	1.2	1.4	0.8		0.6	
Z Corrosion Repair				3.2		
F Repair		5.0	1.5			1
P Remove		0.5	0.8			

TABLE 32. DISTRIBUTION OF C-141A CORROSION MAINTENANCE RECORDS AT TRAVIS AFB AMONG HOW-MALFUNCTION AND ACTION TAKEN CODES, 4Q70-4Q74. VALUES ARE RECORDS PER AIRCRAFT PER QUARTER.

	How Malfunctioned					
Action Taken	230 Dirty	190 Cracked	846 Delaminated	170 Corroded Mild	117 Deteriorated	865 Coating Sealant
V Cleaned	8.1					
G Repair/ Replace	0.4	13.0	4.0	1.4	0.8	0.4
R Remove & Replace	0.1	2.3	2.0		0.6	
Z Corrosion Repair				4.1		
F Repair						
P Remove		0.6	0.5			

TABLE 33. DISTRIBUTION OF C-141A CORROSION MAINTENANCE RECORDS AT NORTON AFB AMONG HOW-MALFUNCTION AND ACTION TAKEN CODES, 4Q70-4Q74. VALUES ARE RECORDS PER AIRCRAFT PER QUARTER.

	How Malfunctioned					
Action Taken	230 Dirty	190 Cracked	846 Delaminated	170 Corroded Mild	117 Deteriorated	865 Coating Sealant
V Cleaned	5.9					
G Repair/ Replace		9.0	3.0		0.2	
R Remove & Replace	0.4	0.8	0.6			
Z Corrosion Repair				5.8		
F Repair		6.2	2.7			
P Remove		0.4	0.7			

TABLE 34. DISTRIBUTION OF C-141A CORROSION MAINTENANCE RECORDS AT ALTUS AFB AMONG HOW-MALFUNCTION AND ACTION TAKEN CODES, 4Q70-4Q74. VALUES ARE RECORDS PER AIRCRAFT PER QUARTER.

	How Malfunctioned					
Action Taken	230 Dirty	190 Cracked	846 Delaminated	170 Corroded Mild	117 Deteriorated	865 Coating Sealant
V Cleaned	1.9					
G Repair/ Replace						3.3
R Remove & Replace	0.6	2.0	0.4			
Z Corrosion Repair				6.6		
F Repair		9.0	3.9			
P Remove		1.2	0.5			

TABLE 35. DISTRIBUTION OF C-141A CORROSION MAINTENANCE RECORDS AT CHARLESTON AFB AMONG HOW-MALFUNCTION AND ACTION TAKEN CODES, 4Q70-4Q74. VALUES ARE RECORDS PER AIRCRAFT PER QUARTER.

	How Malfunctioned					
Action Taken	230 Dirty	190 Cracked	846 Delaminated	170 Corroded Mild	117 Deteriorated	865 Coating Sealant
V Cleaned	3.6					
G Repair/ Replace	0.1	13.5	7.4	0.3	0.9	3.6
R Remove & Replace	0.6	2.0	1.2		0.9	
Z Corrosion Repair				6.6		
F Repair						
P Remove		0.4	1.4			

TABLE 36. DISTRIBUTION OF C-141A CORROSION MAINTENANCE RECORDS AT McCHORD AFB AMONG HOW-MALFUNCTION AND ACTION TAKEN CODES, 4Q70-4Q74. VALUES ARE RECORDS PER AIRCRAFT PER QUARTER.

	How Malfunctioned					
Action Taken	230 Dirty	190 Cracked	846 Delaminated	170 Corroded Mild	117 Deteriorated	865 Coating Sealant
V Cleaned	1.5					
G Repair/ Replace	0.5	13.0	6.9	0.5	1.6	
R Remove & Replace	0.5	0.5	0.4		0.4	
Z Corrosion Repair				29.9		
F Repair						
P Remove	0.4	0.7	1.2			

less than 1/3 of the total--receiving action "remove and or replace." Likewise How-Malfunction 170, corroded mild, generally is corrected by action Z "corrosion repair," a small fraction receiving action G, repair and replacement of minor parts.

The entire set of Tables 31 through 36 reveals a similar pattern for How-Malfunction 230 and 170. Dirty generally is cleaned, and corroded generally is corrected by corrosion repair. How-Malfunctions 190 cracked and delaminated 846 receive a variety of actions including G, repair and or replacement of minor parts, R, remove and replace, F, repair, and P remove. How-Malfunction codes 117 deteriorated and 865 coating sealent seem to generally receive an Action Taken of repair and or replace, code G, or remove and replace, code R.

We have converted the data of Tables 31-36 into a slightly different form. In Table 37 are listed the ratios of how-mal codes 230 to action taken "clean", and how-mal code "corrosion" to action taken "corrosion." How-Malfunction codes cracked 190, delaminated 846, deteriorated 117, and coating sealant 865 have been listed instead as a summation, since it is not clear for the indivudual Action-Taken code which specific how-mal code gave rise to it. Accordingly we have listed in Table 37 by airbase and by When-Discovered the ratios of action G, F, R, and P to the summations of the remaining How-Malfunctioned codes. Consequently, Table 37 shows by airbase essentially what actions are taken for the various How-Malfunctions as a function of when they are discovered.

Table 37. Ratio of Selected C-141A Action-Taken Codes[1] to How-Malfunction Codes[2] separated by Airbase and When Discovered 4Q70 to 4Q74.

A. McGuire AFB

	V/230	Z/170	G/Σ[3]	F/Σ	R/Σ	P/Σ
K - Minor	0.69	0.99	0.48	0.34	0.20	
M - Major	0.69	0.94	0.52	0.30	0.18	
F - Between Flights	1.8	0[4]	0.49	0.28	0.16	
S - Depot	0.78	0	0.39	0.42	0.18	

B. Dover AFB

	V/230	Z/170	G/Σ	F/Σ	R/Σ	P/Σ
K	0.90	0.99	0.91			
M	0.82	0.98	0.90			
F	___ [4]	___	0.87			
S	0.85	0.96	0.94			

C. Travis AFB

	V/230	Z/170	G/Σ	F/Σ	R/Σ	P/Σ
K	0.96	0.97	0.90		0.1	
M	0.95	0.96	0.88		0.1	
F	--	--	0.58		0.32	0.08
S	0.93	--	1.4		0.11	

D. Norton AFB

	V/230	Z/170	G/Σ	F/Σ	R/Σ	P/Σ
K	0.95	0.97	0.53	0.39		
M	0.96	0.97	0.50	0.41		
F	0.97	--	0.41	0.34		
S	0.93	0.98	0.59	0.27		

Table 37. Cont'd

E. Charleston AFB

	V/230	Z/170	G/Σ	F/Σ	R/Σ	P/Σ
K	0.87	0.96	0.88		0.09	
M	0.89	0.97	0.88		0.09	
F	1.0	--	0.72		0.23	0.07
S	0.88	1.0	0.87		0.08	0.07

F. Altus AFB

	V/230	Z/170	G/Σ	F/Σ	R/Σ	P/Σ
K	0.79	1.0		0.69		
M	0.62	0.99		0.69		
F	0.71	--		0.47		
S	0.66	0.99		0.73		

G. McChord AFB

	V/230	Z/170	G/Σ	F/Σ	R/Σ	P/Σ
K	0.57	0.98	0.91			
M	0.47	0.99	0.92			
F	0.72	0.72	0.81			
S	0.50	0.98	0.92			

Note (1) Action Taken Codes used are V-Clean, G, Repair and/or Replace, R-Remove and Replace, Z-Corrosion Repair, F-Repair, and P-Remove.

Note (2) How Malfunction Codes used are 230-Dirty, 190-Cracked, 846-Delaminated, 170-Corrosion (mild to moderate), 117-Deteriorated, and 865-Coating, Sealent.

Note (3) Σ indicates that the denominator is the sum of How Malfunction Codes 190, 846, 117, and 865.

Note (4) A zero entry indicates a zero numerator but non-zero denominator. A / entry indicates both numerator and denominator too small to be significant.

The ratios Z to 170 in most cases are greater than 0.9, indicating that How-Malfunction code corrosion generally receives a corrosion repair. A single low value under McChord AFB for between-flights ground-crew inspections is probably not significant. The absolute numbers of records involved are not large and the apparent difference amounts only to about 25 records. The same thing can not be said for the zero entries under McGuire AFB, since there are 476 and 113 how-malfunction records discovered at depot and between-flights ground-crew, respectively. In general, however, it may be said that there is a nearly 1-to-1 relation between How-Malfunction-Corroded, and Action-Taken - corrosion repair.

A similar but slightly weaker statement may be made concerning How-Malfunction 230 dirty and Action V cleaned at Travis and Norton AFB's. The correlation is nearly as good as was the case for the corrosion codes and at Charleston and Dover AFB the relation still is strong. At Altus, McGuire, and McChord AFB's however, there appears to be a relatively weak correlation between the How-Malfunction codes and the Action Taken code. One wonders why the relation between "dirty/needs to be cleaned" is weaker than that between "corroded/requires a corrosion repair." A corroded component might be expected to require replacement more frequently than would a dirty component. Perhaps there is a psychological factor at work here such that the person who "repairs" something has greater dignity than the one who merely "cleans." Edmund Burke (30) chide an individual who said that

"....all occupations (are) honorable. If he meant only that no honest employment was discraceful, he would not have gone beyond the truth....The occupation of a hairdresser or of a working tallow-chandler cannot be a matter of honor to any person---to say nothing of a number of more servile employments."

In any case the records do seem to show that "dirty" does not always get cleaned. Corroded, however, almost always receives a corrosion repair.

For the rest of the ratios, if there is not outright confusion at least there is little agreement concerning the use of Action-Taken codes. For the How-Malfunction codes 190 cracked, 846 delaminated, 117 deteriorated, and 865 coating sealant, etc., we find the following patterns

A. McChord and Dover most of the time (over 90%) use G, repair and or replace, with the balance of cases scattered among several action taken codes.

B. Charleston and Travis AFB's also are fond of code G but concentrate the balance of cases in R, remove and replace.

C. Norton used code G with code F, repair, in the approximate proportions 50 to 40.

D. Altus leans strongly on the use of code F, about 70%, and divides the remainder about equally among G, R, and P remove.

E. McGuire employs G, F. and R in the approximate proportions 50, 30, and 20 respectively.

Clearly the action taken codes are redundant in some cases, for example, How-Malfunction code 170 corroded, and Action Taken Z, corrosion repair, and the two "cleaned" codes, 230 and V. If the appropriate combination of How-Malfunction codes and Action Taken code is used, the same information is provided. Such repetition may serve a useful purpose (recall

that there is an additional how-malfunction code designator added at the end of each record by HQ AFLC). The purpose for repeating the data, however, is not obvious.

The action taken codes are not particularly informative; for example, what does the Action-Taken G, repair and or replacement of minor parts, mean when it is associated with How-Malfunction code 190, cracked. Was the crack repaired? Was it welded? Was a mending plate affixed? Was the cracked part replaced with a new part or perhaps a cannibalized part? The use of code G is restricted to minor parts, indeed not merely minor parts, but "bits and pieces." (22) At some airbases, e.g., McChord, everything appears to have been a bit or a piece, whereas at Altus, nothing was a bit or piece. We should not be hasty to critcize maintenance personnel for improper use of these codes. The instructions for their use are not absolutely clear. The first words in the instructions for Code F are "repair; not to be used to code on equipment work....if another code will apply." Maintenance personnel might quickly scan the page to see what other codes might apply. Doing so, one will find only two codes which include the word "repair": Code G, repair and or replacement of minor parts (bits and pieces), and Z, corrosion repair. One is on the horns of a dilemma: did he repair something "on equipment" or a minor part. Pressed for time, he will not take the time to read further and will fall into a habit of using the same code for every job. The data of Table 37 shows clearly that the

use of the same code for all situations does become a base-wide habit.

We draw two conclusions from Table 37. First, base practices concerning work classifications in data reporting are widely variable from one base to another. Second, the action taken codes are of marginal value.

The final analysis performed on the maintenance data base was to determine how the use of certain code groups varied from one year to another at field-level maintenance. Accordingly the maintenance records were separated according to airbase, then further subdivided by Work-Unit code groups, by selected How-Malfunction Codes (HMC), and by calendar year. Normalized to records per aircraft per quarter and manhours per aircraft per quarter, the data then were graphed against calendar year. Since only two quarters of data were available for 1970, the plotted values were obtained by doubling those numbers, perhaps a questionable procedure. The resulting charts being somewhat confusing, only five examples are shown in Figures 38, 39, and 40. The entire set of these charts illustrate the extent to which these codes were used at the various airbases as well as the variation in use over a five year interval. In every case where there has been a change in the number of records per aircraft per quarter, there has been a corrosponding but larger change in the manhours value. With a few exceptions, there was a uniform reduction in both records and manhours in 1972-73. Occasionally, this reduction was fairly dramatic.

The data are divided into three sets of graphical presentations. The first set shows the level of use for HMC's 170,

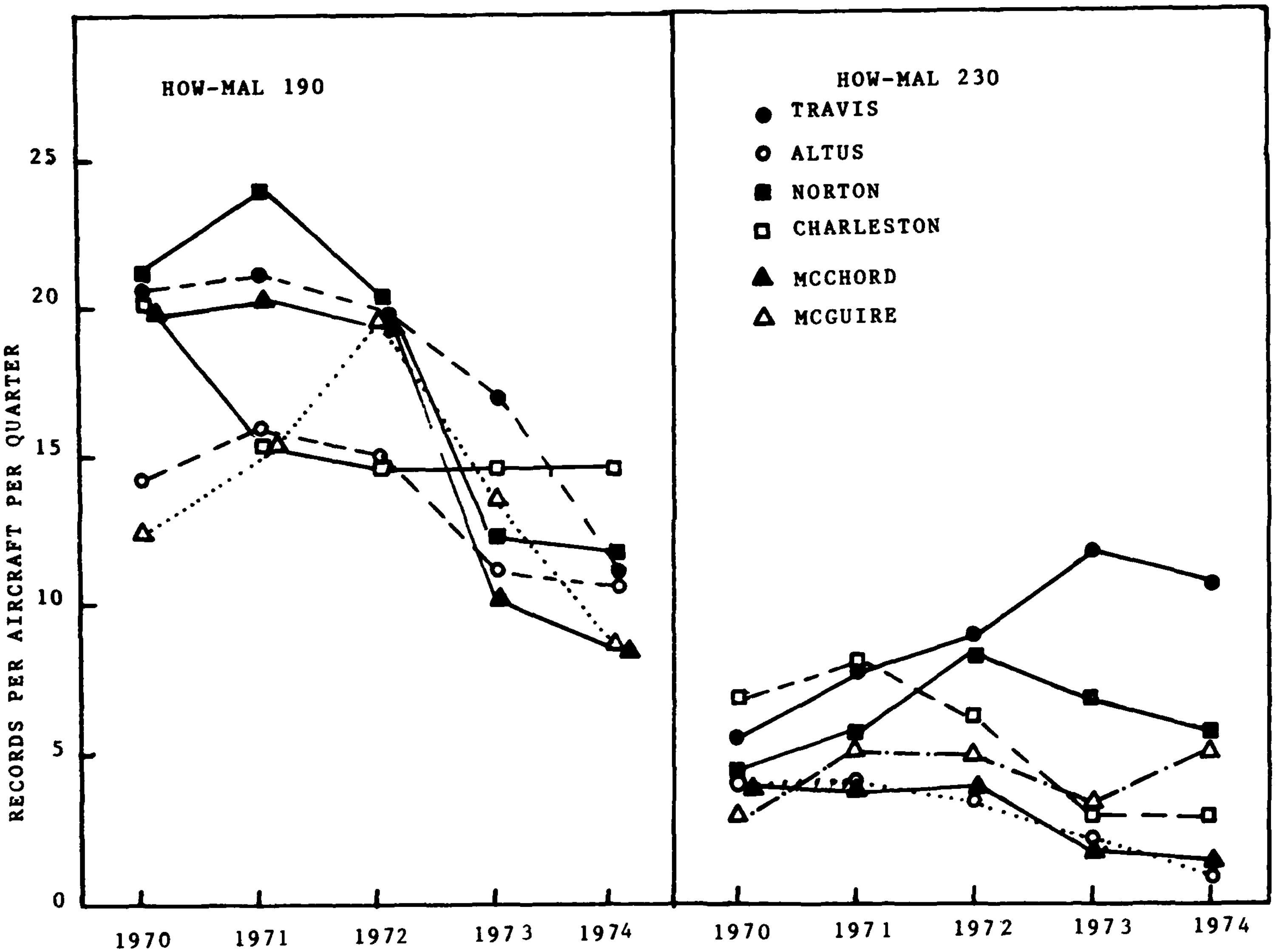

FIGURE 38 . FREQUENCY OF HOW-MALFUNCTIONED CODES 190 and 230 BY AIRBASE AND BY YEAR FOR ALL WORK UNIT CODES, C-141A AIRCRAFT.

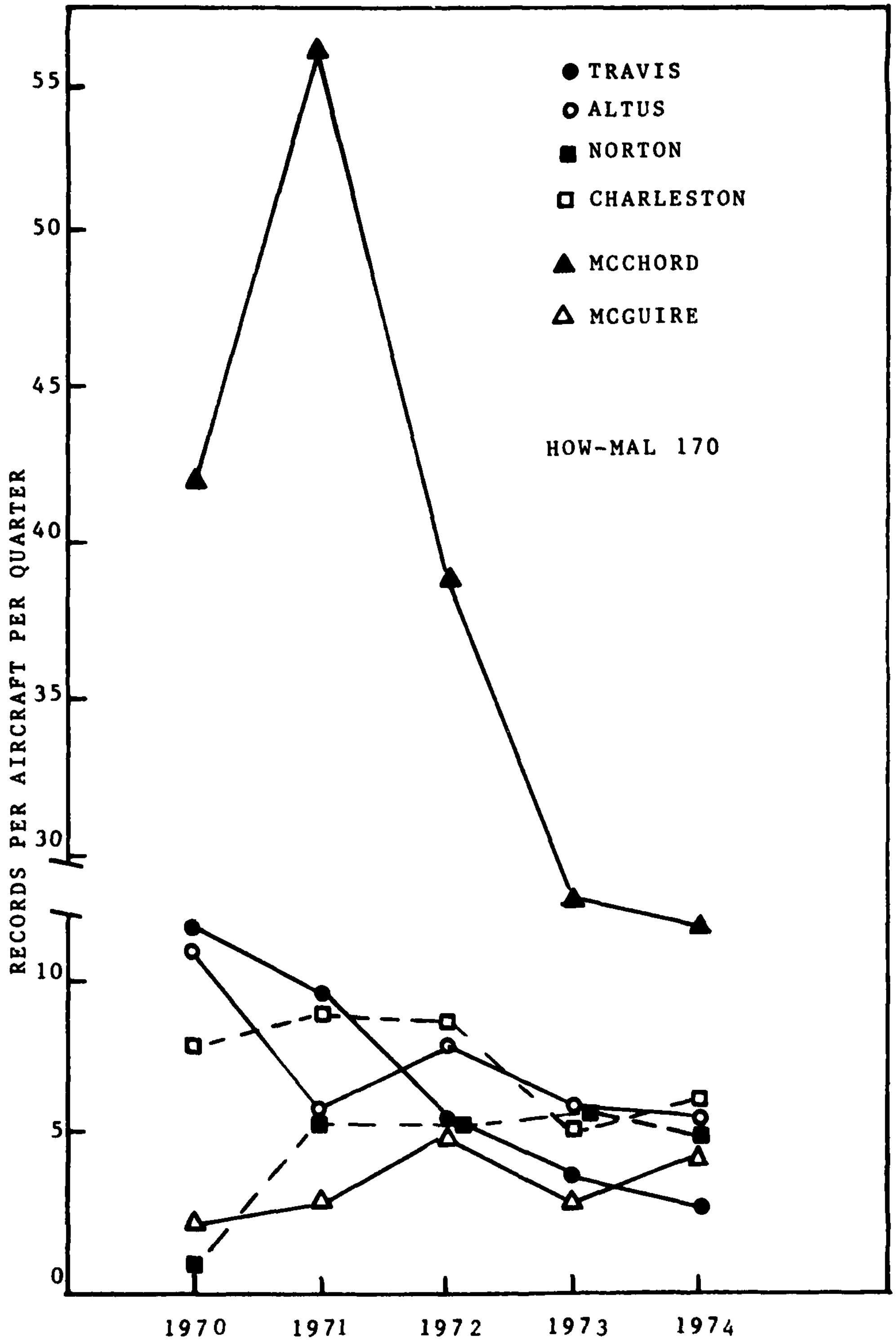

FIGURE 39 . FREQUENCY OF HOW-MALFUNCTION CODE 170 BY AIRBASE AND BY YEAR FOR ALL WORK UNIT CODES, C-141A AIRCRAFT.

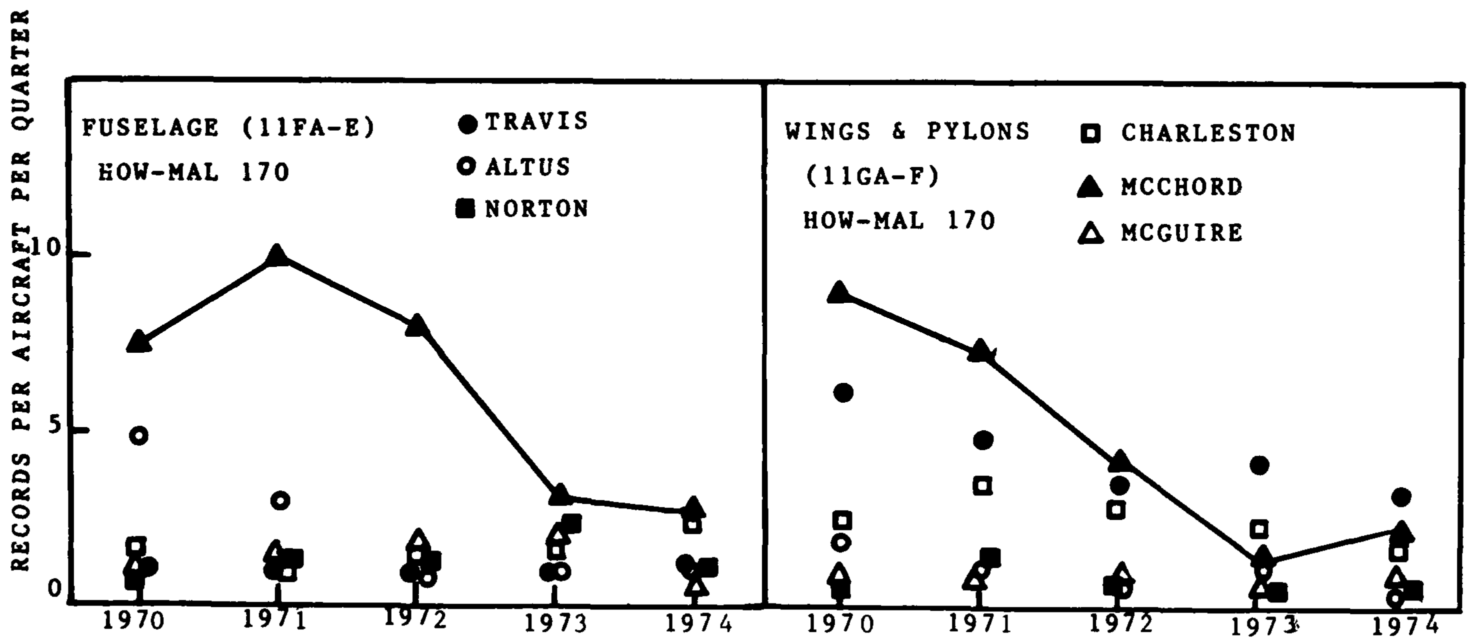

FIGURE 40 . FREQUENCY OF HOW-MALFUNCTION CODE 170 BY AIRBASE AND BY YEAR FOR SELECTED AREAS OF C-141A AIRCRAFT.

190, 230, and 846, for all aircraft components (Figures 38 and 39 are typical examples). Code 190 was found to have been used most frequently, as has been noted previously, but its use also has fluctuated more widely from year to year. Second most frequently used was HMC 846, which showed increases in use at Altus, Charleston, and McGuire AFB's, but decreases at McChord, Norton and Travis AFB's. Third and fourth most frequently used codes were 170 and 230, respectively.

The second set of charts shows the variability of use of HMC's 190 and 170 on selected components: (1) fuselage, (2) wings and pylons, and (3) ailerons/flaps (an example is Figure 40). These generally show decreased useage from year to year, except at Charleston AFB, where values remain roughly constant or increase. Altus AFB exhibits the smallest variation, whereas Norton and McChord AFB's have the largest. (The latter two, of course, are related to the well-discussed anomalies.) At Travis AFB there occurred a large decrease in the use of HMC 170 on wings and pylons between 1972 and 1973. Code 190 is the most frequently used code, mainly on fuselage repairs. Distinctions between the remaining codes generally are not worth the trouble to make, except to note the large use of Code 170 at McChord.

The third set of charts (not illustrated) shows Work Unit codes groups useage and time dependence over all How-Malfunction codes. It should be remembered that the parts-group size (i.e., their relative numbers), as well as frequency of failure/repair, contributes to the levels of code useage. Fuselage repairs are largest in number as well as largest in

variation. In second place are wings and pylons; ailerons/flaps alternate with various door categories for third and fourth places. Altus AFB exhibits an exceptional case, however, where fuel tank repairs (nearly all bearing HMC 865) were dominant. Second was ailerons/flaps, followed in order by fuselage and wings/pylons.

Additional Comments on Each Specific Airbase:

Altus AFB: HMC 190 had both greatest use and largest variations with time, followed by HMC 846. The latter showed a tendency to increase with time. HMC 865 shows virtually no activity in 1971, very high levels of activity in 1972, 1973, 1974, but falling again to nearly zero in 1975. This code is associated exclusively with fuel tank work.

Charleston AFB: The largest changes occur in HMC 170 and 190, with sharp decreases in the years 1973 and 1974. One might surmise that, if these changes were the result of a reduction in flight hours, one would find proportional changes in the other codes. This does not seem to be the case, suggesting that changes in reporting practice and/or work classifications are the primary source of variation in the data.

Norton AFB: HMC 190 shows the greatest variation. The major source of the variation is in fuselage repairs, which decreased until 1973, but then increased. The remaining parts groups are relatively constant or slightly declining.

Travis AFB: Along with McChord AFB, it shows the sharpest decreases in the amount of work done on fuselage and wings/pylons, but again HMC 190 shows the greatest use and the greatest variation.

McGuire AFB: Fuselage repairs are larger than for any other parts groups as well as for the use of HMC 190. In this and in other measures the trends at McGuire AFB are typical.

SECTION X.

AIRCRAFT UTILIZATION HISTORIES

Early speculation about the causes of variable corrosion experience among aircraft included the possible roles of mission. Subsequent to October 1, 1969, the Air Force has collected certain flight data by serial number as part of an Individual Aircraft Service Life Monitoring Program (IASLMP). (31) The primary purpose of the program is to track individual aircraft-loads experience and hence structural fatigue. The data collected consist of actual time each aircraft spends in several flying conditions (high-altitude cruise, etc.) and various loading factors at the relevant times. Although this data is related loosely, if at all, to corrosion damage, it is the only information available which describes in any way how the aircraft have been used.* Accordingly, they have been analyzed to some extent to determine how they might compare with the maintenance histories.

The Mission Profile Records were made available on two reels of tape, one covering the time period 1966 through CY 1972 and the second CY 1973 through the first quarter of 1975. Unfortunately, the two sets of records are not compatible because the mission profiles were redefined. Both sets contain the same basic types, however, e.g. training, long range logistical support, etc. Listed in Table 38 and 39 are the data parameters and mission identification for these two data sets.

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*Individual logbooks might be consulted and hour-by-hour correlations made with atmospheric/environmental parameters. Even Schoch (31) did not consider this approach reasonable in constructing past utilization histories.

Table 38. Parameter and Mission Profile Identification for Fourth Quarter CY 1969 through Fourth Quarter CY 1972.

Parameter	Mission	Identification
1		Serial Number
2		Total flight hours
3	1 a	Logistical, medium range
4	1 b	Logistical, short range
5	2	Logistical, long range
6	3 a	Training
7	3 b	Training
8	4	Air drop, long range
9	5	Logistical air drop, long range, immediate landing
10	6	Logistical air drop, medium range
11	7	Logistical air drop, short range
12	8	Miscellaneous mission, with air drop
13	9	Flight test
14	10	Joint and Unilateral Airborne training
15	11	Low level navigational training
16		Minuteman Mission
17		Terminal Landings
18		Total Landings

Table 39. Parameter and Mission Profile Identification for First Quarter CY 1973 through First Quarter CY 1975.

Parameter	Identification
1	Serial Number
2	Total flying hours
3	Total landings
4	Full stop landings
5	Touch and go landing
6	Mission 1 medium range logistics, average payload
7	Mission 2 medium range logistics, high payload
8	Mission 3 short range logistics, low payload
9	Mission 4 short range logistics, average payload
10	Mission 5 short range logistics, high payload
11	Mission 6 short range logistics, average payload, high fuel
12	Mission 7 long range logistics, maximum take-off weight
13	Mission 8 position for channel
14	Mission 9 training
	Mission 10 training with air drop
	Mission 11 air drop
	Mission 12 flight test
	Mission 13 airborne training
	Mission 14 low level navigator
	Mission 15 minuteman mission

On examination, it was found that several mission categories had very small values (often zero) for every aircraft in the force. These categories were parameters 8 through 15 of Table 38 and parameter 15 through 20 of Table 39. Accordingly, these parameters were not used in any analyses.

The aircraft were studied according to the number of flying hours each serial number had accumulated within each mission parameter using the cluster analysis technique. In this method, objects having statistically similar values for a variety of parameters are grouped together into cells. In this case, one wishes to determine which aircraft have had flying hours similarly distributed among the several mission parameters. Such a cell of aircraft, having similar utilization histories, then might be compared to see whether their corrosion repair histories or some related characteristic also are similar.

A computer program, CLUSTR (developed by Adaptronics, Inc., McLean, VA), was used for these analyses, and, applied to parameters 2-7, 17, and 18 of the 1969-72 data, produced the results of Table 40. The aircraft divide themselves into seven cells, each with a different profile distribution among the eight mission parameters. These profiles are shown as bar graphs in Figure 41, where the height of each bar is the ratio of the cell mean to the average of all cells for each parameter. The seven cells are characterized as the following five types:

(1) High flying hours in both short and long range logistical missions, cell 3. This group is comprised of McChord-and Travis-based aircraft, but also includes

Table 40. Results of Cluster Analysis on Mission Profile Data 1969-1972, Selected Mission Parameters

		MEAN VALUE OF PARAMETERS								DISTRIBUTION BY BASE						
		TOT F HRS.	LOG MED RNG	LOG SHT RNG	LOG LNG RNG	TRAIN	TRAIN	TERM LDGS	TOT LDGS	ALTUS	CHARLESTON	DOVER	MC CHORD	MC GUIRE	NORTON	TRAVIS
Cell	Pop.		1 a	1 b	2	3 a	3 b					3	5	6	7	8
1	24	5084	2700	1182	403	269	489	1301	2093		3	4		14	1	2
2	9	5499	2905	1183	381	435	421	1329	2014			2		7		
3	99	6139	2291	2021	1016	311	489	1590	2315		4		39 (2 errors)		13	41
4	56	5983	3395	1318	416	344	466	1497	2119	1	7	12		35 (1 Robins)		
5	61	6305	2916	1894	502	305	629	1671	2512		25			(1 Robins)	34	1
6	10	4276	1285	819	295	405	1447	1165	4350	4			1	3	2	
7	11	3670	425	291	119	480	2343	1124	6148	11						

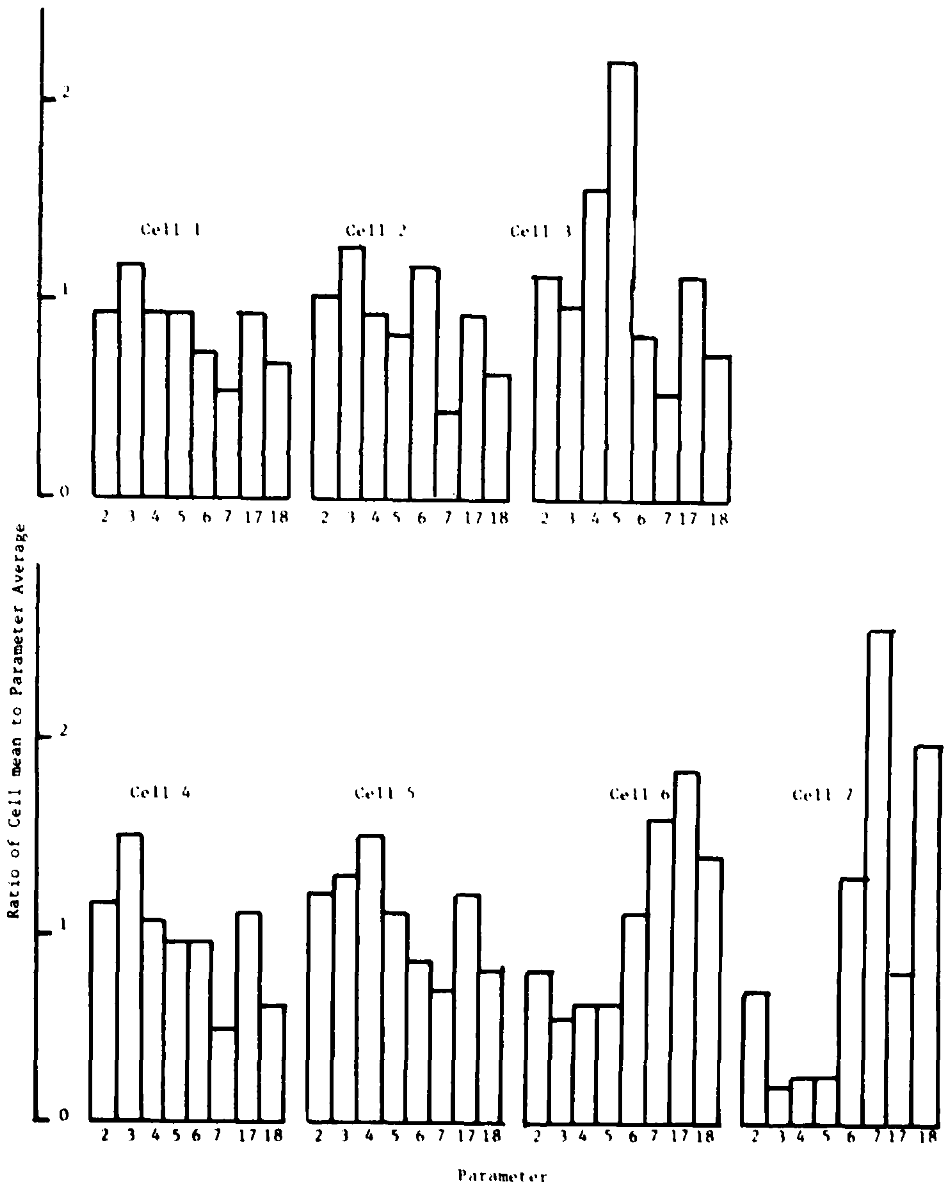

Figure 41. Results of Cluster analysis on mission profile data 1969-72, selected mission parameter.

a significant number of Norton based aircraft. Of these latter, however, most had been transferred to Norton from Travis or McChord.

(2) High flying hours in medium range logistical missions, cells 1, 2, and 4. The populations in these cells mostly are McGuire-and Dover-based aircraft.

(3) High flying hours in medium and short range logistical missions, with a high count of total landings, cell 5. These are almost entirely Charleston-and Norton-based aircraft.

(4) High flying hours in training missions with a high number of total landings, but low total flying hours and low flying hours in logistical missions, cell 7. Clearly these are training mission aircraft, and all were based at Altus AFB.

(5) High training flying hours with some medium range logistical missions, cell 6. Mixed assignments, except all but three of them had been stationed at Altus for part of the time period.

Analysis of the 1973-75 data produces essentially the same results. Hence, in terms of mission profile, we find the combinations of:

- McChord with Travis
- McGuire with Dover,
- Charleston with Norton and
- Altus alone.

Utilization patterns, like corrosion maintenance histories, are base-characteristic. The combinations which result from mission profile analysis however, are quite different from those of the maintenance data analysis. Although substantial amounts of time and effort were spent in attempts to derive more meaningful correlations with utilization data, none were produced. It was concluded, ultimately, that mission profile data collected under IASLMP can be nothing more than a small perturbation on the corrosion problem. Efforts to relate the two data sets were abandoned.

SECTION XI

SUMMARY

The maintenance histories of individual C-141A aircraft show wide variations in the extent of corrosion-related maintenance over a six and one-half year period. These histories, together with all available data on aircraft utilization, have been analyzed extensively to determine the causes of these differences. Operational environment clearly has a role in the problem, but other factors, such as local management policies and peculiarities of the Maintenance Data Collection System itself, are equally significant in determining the volume of apparent maintenance that enters the repair records. The existing repair records can not be used as a quantitative measure of past corrosion maintenance or of the extent of corrosion damage.

The best predictor of maintenance effort is the base to which an aircraft is assigned. There are wide variations from aircraft-to-aircraft at the same base, differing by as much as a factor of two in the level of corrosion maintenance. No operational factors account for these differences, and the extent of corrosion repair seems to be distributed randomly among any given population. This would be expected, over long time intervals, for a "seasoned" (i.e., between break-in and wear-our periods) aircraft population, such as the C-141A force. A random distribution is consistent with the conclusions of Bell and Stucker (11), that malfunctions and the correction thereof occur randomly. Repair times, moreover, even for apparently similar actions, on seemingly identical aircraft may vary widely.

Variations in the level of maintenance effort at an airbase, over short time intervals (i.e., year-to-year), probably reflect policy changes in data reporting and/or the type of work done. The most probable phenomenon effective is that of "course overcorrection," where the discovery that a unit is spending large and unscheduled efforts on certain categories of work is followed by a drastic reduction thereof. Although not documented, this is the suspected cause of the Altus and McChord Anomalies. A similar correction in depot operations is documented (29), however, with the results illustrated in Figure 37.

Even wider differences are observed in reported maintenance effort from one airbase to another. Some of these differences are explicable where data gaps have occurred (Norton Anomaly). In such cases where no data exists over extended time periods, it is obvious that the records are faulty. In the case of an apparently normal set of records, however, one can not be sure what fraction of the total effort actually is accounted for. We know, for example, that structural modifications do not enter the AFM 66-1 records (32). Records of these do exist, and, to the extent that they are corrosion-induced, they could be accountable. Maintenance recorded under Support General Work Unit Codes is lost, however, and the extent of their use is an unknown variable. Clearly, the MDC System is not collecting all maintenance data and there are no reliable estimates of what fraction is recovered.

A partial suggestion of an answer may be obtained by comparing the AFM 66-1 data with field maintenance reports.

The latter are published as the monthly "Maintenance Digest (RCS-MAC-LGX (M) 7103). Comparing these, base-by-base and month-by-month, for the six airbases could provide a calibrating factor. Only one of the 468 relevant "Maintenance Digests" was available, however, this one from Travis AFB for July, 1976. In these reports, generated via BLIS, maintenance data are detailed according to Performing Work Center (Organizational Element), and included are authorized and assigned personnel, and distribution of manhours. As noted previously, the loss of the Performing Work Center information in the permanent records precludes a complete comparison of the two data sets. An indirect comparison is possible, however.

Work performed by FMS Corrosion Control Shop, in all probability, will be coded with a corrosion How-Malfunction or Action Taken code. To be sure, other shops also might use these codes, but the probability seems small. Accordingly, one can compare manhours bearing these codes in the permanent records with the manhours reported in the monthly Digest for the same month.

Corrosion Control (Q314-60th MAL WING) at Travis AFB was credited in July, 1976, with a total of 2467 manhours on C-141A aircraft. Reported by R314-349th MAL WING were an additional 558 manhours. Thus, either 2467 or 3025 manhours could have reached HQ AFLC bearing How-Malfunction code 170 or 667, or Action Taken code Z. The actual number of these in the AFM 66-1 data file for July, 1976, are 907 and 842 manhours,

respectively. Thus, the Maintenance Data Collection System at that time apparently recovered between 28 and 37% of the man-hours it is designed to collect (cf. footnote, page 12).

Several additional factors bear on the maintenance variability question.

- -Preventive maintenance, properly reported under Support General codes. An especially effective program would prevent deterioration, hence reduce the volume of repair work needed.
- -Repair work improperly reported as Support General falsely represents the volume of repair work accomplished.
- -The effectiveness of inspections. If a discrepancy is reported, obviously it must have been discovered, usually during an inspection. Conversely, it must be discovered before it can be reported.
- -The scope of individual documentation. Sometimes two records are written when only one is needed, or vice versa.
- -Real differences in failure rate which result from variable corrosiveness of the environment.

Existing documentation provides little guidance for separating these significant quantities from one another or from factors such as:

- -the emphasis placed by management on corrosion control programs, or
- -the fact that command at certain airbases is an upward stepping-stone, hence aircraft are kept better looking (33).

Allowing for these considerations as much as possible, the maintenance data combined with direct observations show that the environment is more corrosive at some airbases than at others. Field maintenance shows Travis and Charleston AFB's to be severe, whereas McGuire and Altus AFB's appear to be relatively mild. It is difficult to make quantitative comparisons, but there are two things which would enhance our ability to do so. First, a comparative analysis should be made of the atmospheric/environmental data at the relevant airbases. This data was collected, but not studied because of logistical and personnel difficulties. Second, some simple changes in the MDC System would obviate most of the problems in AFM 66-1 data.

The extent of depot maintenance also is more-or-less random over any set of aircraft. Again, no causative factors are found, although there is some relation with the airbase to which aircraft are assigned. Changes in the maintenance "package," from year-to-year and within a fiscal year, do perturb the average for a set of aircraft, but the random nature of the distributions does not change. Package content is determined on a yearly basis, partly from the results of the ACI program. Adherence to the package is not strictly required for every aircraft (32), and exceptions are allowed on a case-by-case basis, hence contributing to the randomness.

Although different mean-maintenance can be demonstrated for sets of aircraft from different airbases, the standard deviations are large. Moreover, the relative ordering of airbases fluctuates somewhat from year to year. These orderings

show Travis AFB still to be relatively severe, Norton AFB worse, and Charleston and McGuire AFB's the mildest. Observations at depot are complicated, since one can not be sure which bases have the most successful corrosion control program.

With respect to PDM-interval extension, the corrosion data do not argue compellingly either pro or con. The data show that aircraft on 42-month intervals did not have different corrosion repair histories than 36-month aircraft. The 48-month CIE aircraft, however, received somewhat high levels of depot maintenance. Accordingly, an extension to 42 months is not contraindicted by the corrosion data alone. Cohen (13) argues that an extension is appropriate in such cases, given close monitoring of the force condition. He notes that a sudden change in the interval does not suddenly change the condition of the force. Instead, several years are required before interval extension impacts the entire force, allowing time to reverse the action if warranted. The dollar benefits, on the other hand, are immediate, and provide the option of cost reduction in the depot program or providing greater depth of maintenance at the longer interval.

An Assessment of AFM 66-1 and the MDC System

The maintenance data collection system and the relevant AFM 66-1 material are a "general-purpose tool", adaptable to any aircraft, any missile, any drone, all aerospace ground equipment - indeed, every sort of equipment held in inventory by the Air Force. The advantages of a general-purpose tool are versatility and adaptability. But versatility is also a

major weakness. A general-purpose tool performs many tasks, all more-or-less inefficiently. In contrast, a special-purpose tool is designed to perform only one or two tasks, which it does effectively. Obviously, any tool must compromise between versatility and effectiveness. If many, relatively unimportant jobs are to be done, then a general-purpose tool is appropriate. If, on the other hand, a few important tasks must be performed on a large and costly system, then specialized tools are more appropriate.

A force of aircraft should be in the latter category. It is costly, complex, and of small size. The tracking of aircraft maintenance is an important matter, and it is inappropriate to track these costs with a maintenance data collection system that is equally effective when applied to Ford pick-up trucks as it is when applied to Lockheed C-141A aircraft. Probably it would be unwise to develop a special purpose MDC system for each MDS aircraft. But, since aircraft are the sine qua non of the Air Force, a special-purpose, aircraft-only MDC system should be developed.

The MDC system and AFM 66-1 seem to have two major purposes:

- to support base-level management decisions; and
- to maintain quality control, hence force reliability and effectiveness.

Both of these primarily are of local significance, contrasted with force-wide importance. Problems of the latter type would relate to overall cost considerations, data collection for the purpose of tracking repairability, and maintainability aspects.

The tracking and prediction of, say, corrosion problems is a specific example of a "global" question which might have been a design objective of MDC and AFM 66-1. It is stated frequently in the relevant manuals that such purposes indeed are to be served by the system. As this study has shown, however, the system is not highly effective in this role.

Whether MDC and AFM 66-1 were designed explicitly to provide data inputs for global management decisions (as at HQ AFLC) is not clear. The output of any management information system may fail to coincide with expected outputs for a variety of reasons, e.g., malfunction of the system, the fact that it was designed to produce a different output, or it was designed poorly. In dealing with an old system, moreover, we must consider its ability to deal with static processes <u>versus</u> dynamic processes and its adaptability to newly defined objectives (such as corrosion tracking and prediction).

In any case, MDC and AFM 66-1 are not the most efficient sources of data for developing a corrosion control loop. With relatively minor modifications, however, it can be made effective for this purpose, as well as for others of a similar nature. Recommendations for such modifications will be listed as a separately-published appendix to this report. These modifications would be more extensive than, for example, simply adding a new How-Malfunction code to the already ponderous list of existing codes. Indeed, there are sound arguments in favor of a "<u>from the ground up</u>" overhaul of the system. But, so drastic a change would take too much time to be of any early

AD-A057 984 MICHIGAN STATE UNIV EAST LANSING F/G 1/3
CORROSION TRACKING AND PREDICTION FOR C-141A AIRCRAFT MAINTENAN--ETC(U)
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value in predicting corrosion costs. Simpler changes can be effected for this purpose.*

The problems involved are in two general categories: first, the shortcomings of the present management-information system; second, the conditions under which various analytical tools may be employed to eliminate present difficulties and to create a comprehensive management-and policy-planning system. The tools employed will come from a variety of areas, mainly optimal-control theory and time-series analysis. Successful application of these tools would bring the current management reporting effort under control and provide a means of executing long term policy plans. The present system is limited to short-term planning on a local basis, both by design and by the limitations imposed by the current _ad hoc_ collection of data reporting elements. None of these were designed to facilitate comparisons between bases, different operating environments, or different management practices. To achieve such comparisons, it would be necessary to explain fully the observed differences in reported corrosion maintenance rates at the various airbases.

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*One recommended change which should be considered for immediate implementation is a complete editorial revision of Air Force manuals to reduce their volume, and improve their readability and effectiveness. A large library of documentation was accumulated during this study, and it was paralleled by a growing suspicion that little of it ever is read (except, of course, by curious professors). Jablonski (34), in a study for the Air Force, asked "How readable are technical handbooks?" In a survey of AF technicians in Viet Nam, he found "that the _use_ of handbooks was less than we had expected, there was _more guessing_ of information than we'd like to think occurs, and that technicians _do not understand_ technical language even after years of experience." (emphasis added) He laid the blame squarely on the manuals themselves, and showed how to improve them. We can not criticize or improve his recommendations.

Any modeling effort must assume an accurate and viable data reporting system. This assumption has not been fulfilled consistently by MDCS. The difficulties experienced by the Air Force are typical of those encountered in large scale management information systems (35). The present system clearly is the end product of a long evolutionary process. Typically, this means that reports generated frequently will contain nearly identical materials. Much of the information is collected in a fragmentary and incomplete way; each collection effort seems designed to answer some immediate or practical question at some point in the past, but for which no clearcut current use exists.

Examples of such problems may be found in the Work Unit codes, the How-Malfunction codes, and the Action Taken codes. For example, the Work Unit codes provide a general description of the functional part in question. Paralleling this is a system of coordinates describing position (in inches) on the aircraft, referred to as station numbers. The system, however, is two-dimensional, giving coordinates only on surfaces. If one is concerned with a component located in the interior of a wing, for example, the station number system will provide only an approximate location. Further, there are only partial corespondences between the station numbers and the Work Unit codes; that is, only some Work Unit codes are matched to station numbers. Thus, establishing precise locations for many components may not be possible.

If a practical question is asked of the data, such as for a list of corrosion "hot spots", a precise answer can not be

given unless the Work Unit codes were matched previously with the station numbers. Whereas unforeseen design features of the aircraft, particular environmental factors, or corrosion maintenance policies at a given base all may result in corrosion problems in unforeseen areas, we are left without an efficient means of locating them. Problems of this sort create pressures to add more categories to the existing system. Thus, one finds the evolutionary, incomplete and overlapping nature of the MDC system.

These considerations return us to an introductory remark: Who exactly are the information users? What exactly do they need? How much is it going to cost to get that information? Answers to these and other questions could be provided in part by a study of the present codes, with the aim of identifying the users and the effectiveness of the present codes, what revisions are needed, etc. Many of the present codes are used infrequently, if at all. A few codes are used for just about everything. Thus, the large number of code categories and the complex rules for their use are not yielding the discriminatory power intended.

In revising an information system, it is not enough to specify the users, their needs, or the various systems costs. Since we have a complex, interrelated system, trade-offs of various sorts will have to be made among conflicting requirements. Such trade-offs already occur in the present system but not on a basis with any rational foundation, insofar as the overall good of the system is concerned. By way of example

we note that ground crews and other maintenance personnel are required to fill out detailed work forms. Not only does this take time away from the actual work to be performed,* it also interacts with an implicit differential reward system present in the various reporting systems: If detailed work unit specifications are filled out, the airbase receives credit for the work done. In turn, this helps contribute to the size of the next year's budget allocation for additional personnel, support services, etc. However, maintenance personnel can save themselves considerable time by simply writing 02000, general support, on the work order form. Thus, whereas maintenance personnel can free-up a few minutes paperwork-time for every repair, the airbase stands to lose proportionately far more, if such work in not reported correctly. Resolving these difficulties is likely to involve a good deal of effort. We may borrow from Ashby's "law of requisite variety" by noting that complicated systems require complicated methods of description.

Problems do not end here. There is little need to comment on the potential arbitrariness of the How-Malfunction codes. What is "midly corroded" at one airbase may be "severely corroded"

*A major problem relating to corrosion maintenance is the absence of a useful definition for a "unit of work." Unlike the example "removal and reinstallation of an antenna," etc., "corrosion repair" is not defined clearly as to magnitude or difficulty. It might be assumed that manhours of labor would be an effective definition. Unfortunately, the number of records is too large where manhours are indicated as 0.1, i.e., six minutes or less. Since the unit of work is to include the time required to enter data on the AFTO 349, it is clear that the data base contains numerous records where fewer than five minutes were spent on the job.

at another. What is "chipped" in one person's view may be "cracked" in another's.

The most severe problems, however, are found in the Action Taken codes. In their present form, the verbal decision procedures (23) are hopelessly confused, complicated, contradictory, and overlapping. For example, Code F is

> "not to be used to code on-equipment work if another code will apply. When it is used in a shop environment, this code will denote repair as a separate unit of work after a bench check. Shop repair includes total repair manhours and includes cleaning, disassembly, inspection, adjustment, reassembly, and lubrication of minor components incident to the repair when these services are performed by the same work center. For precision measurements equipment, this code will be used only when calibration of the repaired item is required (see code G.)"

Even if maintenance personnel attempted to comply with the conditions imposed on the use of code F, it is difficult to see what useful information would be extracted. These remarks extend to the remaining Action Taken codes. As they currently stand, the Action Taken codes could be scrapped with little loss.

The problems outlined in the previous pages fall into one of three general categories encountered in dealing with management information systems, viz, operational feasibility. Most of the difficulties encountered in the design of such systems are to be found here. There are, however, two other areas, technical feasibility and economic feasibility. Problems associated with the technical feasibility are the easiest to resolve: the technology either is present or not, and if present, the appropriate personnel can get the system running. Traditionally, economic feasibility has been of little direct concern in military operations. Nonetheless, in dealing with

complex systems and competing alternatives among various systems and various reporting requirements, there is considerable room for tests of economic feasibility.

There are a number of elementary considerations and a great many sophisticated considerations that go into reporting system design. All too often it is the elementary considerations that are not given sufficient thought. Among these are the following: first, identify all the reports generated by the computer. How many of these are joint reports?; second, specify the opportunity costs of the system, i.e., what would be the costs if the present system did not exist, or if proposed modifications to it did not occur?; third, where possible, develop formal methods for estimating costs; fourth, are there intangible benefits? If so, what measures will establish their impact? Additional criteria could be added.

The problems mentioned above have limited use of the computer to short-term goals and to largely local-level policy decisions. A reading of the various computer-generated reports listed in AFM 66-1 implies that little more was intended, thus ignoring much of the computer's potential in the management of overall maintenance operations. This need not be the case. Given that the deficiencies in the present codes are corrected, a large variety of analytical tools can be developed and applied to the data.

Behind such tools is a general rationale which attempts to account for the interactions between different airbases, the environmental problems associated with these bases, and the

resulting corrosion rate. The environmental conditions at the various airbases vary widely. There are also differences in maintenance staffing and policy among the various bases. In part, these differences are a response to the wide variance of environmental conditions, and in part they stem from a multitude of factors which render effective control of overall operations difficult.

The cummulative repair history curves of the aircraft stationed at a given base have common characteristics. The various properties of these curves, together with a knowledge of the amount of time spent by these aircraft at different bases, may be used to make inferences about the relative impact of the environmental and managerial factors in operation at the respective bases. The amount of work will depend on the condition of the aircraft upon arrival, and thus upon its previous environmental and management experience. How much work it will receive depends on present management policy and current work loads. The interactions of these effects will determine whether the repair curve will be convex or concave to the orgin. Crudely, if management is "efficient" we would expect, after an initial spate of repairs, that the overall rate would level off to some constant value. On the other hand, if it is not "efficient" we would expect a small pulse, a lag in repairs, and the effects of cumulative corrosion damage to generate an increasing rate of repairs, thus giving rise to a curve concave to the orgin.

Implicit in the above, and in much of what follows, is the idea that the overall corrosion rate is the difference between the environmental impact on the aircraft and the management efforts to compensate that impact. What we can observe is the overall corrosion repair rate. The management and environmental impact on the aircraft and the effects are not directly observable. There are two observable components of management policy: the number of repair records generated and the number of manhours per repair. Assume that environmental effects consist only of two states: mild and severe.

Since we are attempting to analyze the impacts of various policies over time, and the impact of changes in those policies, it is not enough to conduct a time-series analysis of the data. Rather the time-series analysis must be cast in a control-theory format that can handle explicit changes in management policy and delineate the various effects throughout the maintenance operation. This is a formidable task, and it will take several pages to outline the most elementary ideas. However, the range of potential application to the Air Force maintenance operation will be considerable. It will be worthwhile to list a few of these. The mathematical machinery will be sufficient to analyze the effects of, say, various delays (e.g., changes in inspection policy) on the different types of repairs that will occur over time; on the adequacy of various levels of maintenance effort at the different bases; on the overall allocation of resources between different bases, such that some objective function

(say, minimum downtime for aircraft) can be maximum subject to a set of resource constraints. The list can be easily extended.

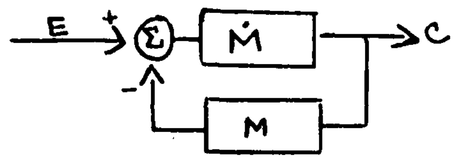
Before proceeding, however, it would be well to go over some basic assumptions. Stated formally our basic assumption is:

(1) $dM/dt = E - M(t) = C(t)$,

where E is the environmentally-induced parts failure-rate due to corrosion (an output)

M is the management effort designed to reduce the impact of E (a controller function), and
C is the corrosion process (an output).

In block diagram form this is:



Typically, the aim is to reduce $dM/dt = \dot{M}$ to zero. However, there are a large number of constraints placed on the controller function, such as insufficient resources, imperfect information, and so forth. There could be situations in which dC/dt is negative, suc' as when an aircraft shifts from a base characterized by inefficient management and severe environmental conditions to one characterized by efficient management and mild environment. At such a juncture, a lot of "deferred maintenance" may occur, thereby limiting the spread of corrosion; the effect would be a negative slope in dM/dt. But for the most part, we would expect dM/dt to have a positive slope. Different circumstances will dictate whether the slope will be a constant or be some function of time as well.

The direction and slope of the various changes, as well as lags in the various slopes, can be grouped into a number of classifications based on characteristics observable from the cumulative distribution curves of repairs for the aircraft. From these we can make inferences about the underlying relations between the controller function, M, and the environmental impact, E. Upon resorting to various techniques from the theory of optimal control, we should be able to determine the specific forms of the M's for the different bases as well as the impact of the respective E's. Insights into the general problems here are afforded by observing changes in the repair history curves of the various aircraft as they cahnge from base to base.

Two general sets of curves exist: first, those derived from aircraft which have been stationed continuously at one base; second, those which have made transitions between one or more bases. Changes in the latter category will yield changes in M and in E, with attendant effects on dM/dt and in the structure of the response lags. In tabular form, these changes may be classified as follows:

	efficient M_1	not efficient M_2
mild, E_1	a_{11}	a_{12}
severe, E_2	a_{21}	a_{22}

Tentatively, we may classify the different airbases as follows:

a_{11} - Altus

a_{12} - McGuire

a_{21} - Travis, Charleston

a_{22} - McChord, Norton

Some additional comments are in order. First, dM/dt is observable only from the number of manhours, and from the number of records per repair. E and M are not directly observable. Thus, special attention must be given to the over-time relations between records and manhours. Second, we have assumed in Eq. (1) that dM/dt is only a first order difference. However, where corrosion effects become cumulative-as they might in the case of cells a_{12} and especially a_{22} - we also might expect an additional contribution in the form of d^2M/dt^2 so that we would have

(2) $A_2 d^2M/dt^2 + A_1\ dM/dt = E - M(t) = C(t)$.

This would give rise to a quadratic equation of the form

(3) $(A_2D^2 + A_1D + 1)\ M=0$,

where $D = dM/dt$.

Thus, changes in the slopes over time can be plotted in the complex plane to determine the stability of the system (e.g., determine the impact of cumulative corrosion damage caused by various types of maintenance policies, the content and frequency of different inspection procedures, etc.)

We have a clear analogy to a mechanical system. In effect, we attempt to measure an equilibrium position by the strength of the restoring action. The stronger the restoring action, the more stable the system.

The simple system described above assumes, however, a great many properties not existent in the system of concern to us. The above system is deterministic and continuous. Our system is neither. It is discrete and probabilistic. For the present, however, little will be lost by continuing to assume continuity. When appropriate, we can make the modifications necessary to effect a discrete sampled data system.

The majority of the complications arise from the assumption that events are probabilistic rather than deterministic. The cumulative repair history curve is a quasi-periodic, compound, stochastic, Poisson process; that is repairs can occur at any time, in any amount, but mostly according to stated intervals for the various types of inspections. Because of changes in base assignment and management-efficiency levels, the probability density and moment-generating functions cannot be assumed to be constant over time, or stationary. Traditional treatment of Poisson processes assumes that only "one" repair can occur in any arbitrarily small unit of time, and that the time of occurrence is random according to an exponential probability distribution (one consequence of using this assumption when it is not valid is an overabundance of stock levels). (34)

Even with the above complications taken into account, there are still some general properties common to the cumulative repair histories when they are classified according to changes in the cells a_{ij}. These are listed in Table 41.

In dealing with actual groups of aircraft and the numerous properties of their respective repair curves, we shall be

TABLE 41. PROPERTIES OF CUMMULATIVE REPAIR HISTORIES

Range	dC/dt before	dC/dt after	initial lag size	change in lag size	curve shape	mean value after	variance after	auto-correlation	auto-covariance	order (1 or 2)	type of stationary
a_{11}	K_1	-	τ_1	-	cv	μ_1	σ_1^2	dec	$\gamma(\tau)$	1	ss
a_{21}	K_2	-	τ_2	-	cv	μ_2	σ_2^2	dec	$\gamma(t)$	1	ss
a_{12}	K_3	-	τ_3	-	cc	μ_3	$t\sigma_3^2$	inc	$\gamma(t)$	2	ws
a_{22}	K_4t	-	τ_4	-	cc	μ_t	$t\sigma_4^2$	inc	$\gamma(t,\tau)$	2	ns
$a_{11}\to a_{21}$	K_1	K_2	τ_1	$\tau_2-\tau_1$	cv	μ	σ_2^2	dec	$\gamma(t)$	1	ss
$\to a_{12}$	K_1	K_3	τ_1	$\tau_3-\tau_1$	cc	μ	$t\sigma^2$	inc	$\gamma(t,\tau)$	2	ws
$\to a_{22}$	K_1	K_4t	τ_1	$\tau_4-\tau_1$	cc	μ_t	$t\sigma^2$	inc	$\gamma(t)$	2	ns
$a_{21}\to a_{11}$	K_2	K_1	τ_2	$\tau_2-\tau_1$	cv	μ	σ^2	dec	$\gamma(\tau)$	1	ss
$\to a_{12}$	K_2	K_3	τ_2	$\tau_3-\tau_2$	cc	μ	$t\sigma^2$	inc	$\gamma(t,\tau)$	2	ws
$\to a_{22}$	K_2	K_4t	τ_2	$\tau_4-\tau_2$	cc	μ_t	$t\sigma^2$	inc	$\gamma(t)$	2	ns
$a_{12}\to a_{11}$	K_3	K_1	τ_3	$\tau_1-\tau_3$	cv	μ	σ^2	dec	$\gamma(t)$	1	ss
$\to a_{21}$	K_3	K_2	τ_3	$\tau_2-\tau_3$	cv	μ	σ^2	dec	$\gamma(t,\tau)$	1	ss
$\to a_{22}$	K_3	K_4t	τ_3	$\tau_4-\tau_3$	cc	μ_t	$t\sigma^2$	inc	$\gamma(t)$	2	ns
$a_{22}\to a_{11}$	K_4t	K_1	τ_4	$\tau_1-\tau_4$	cv	μ	σ^2	dec	$\gamma(\tau)$	1	ss
$\to a_{21}$	K_4t	K_2	τ_4	$\tau_2-\tau_4$	cv	μ	σ^2	dec	$\gamma(\tau)$	1	ss
$\to a_{12}$	K_4t	K_3	τ_4	$\tau_3-\tau_4$	cc	μ_t	$t\sigma^2$	inc	$\gamma(\tau)$	2	ws

Inequalities;

$0=K_1<K_2<K_3<K_4$

$0=\tau_1<\tau_2<\tau_3<\tau_4$

matrix

	M_1	M_2
E_1	a_{11}	a_{12}
E_2	a_{21}	a_{22}

(autocovariance is either a function of or both 't' and τ)

Abbreviations;

cc=concave
cv=convex
ns=not stationary
ss=strict sense stationary
ws=wide sense stationary
sk=stationary, order k, k=1,2,3,...
t=time

dec=decreasing (damp out quickly)
inc=increasing (fail to damp out quickly)

definitions;

mean value $\mu x = \Sigma x_i/N$

variance $\gamma\sim - E\ [\{Xt - \mu(t)]^2\}$

auto-covariance $\gamma\tau = E\{[Xt - \mu(t)]\ [X\tau - \gamma(t+\tau)]\} = \mathrm{cov}\ [Xt_1\ X\tau]$

autocorrelation $\rho\tau = \gamma\tau/\gamma o = \dfrac{\gamma xx(t_1, t\sim)}{\sigma(t_1)\sigma(t_2)}$

required to introduce matrix notation. This will require the introduction of state variable theory. Since there is a practical payoff, such a procedure should not be viewed as another unmitigated abstraction. Rather, it will enable us to use several new performance measures each as the autocovariance, autocorrelation, and cross-correlation matrices. The damping rates of these functions may be used to determine the stationarity of a series, what effects changes in lags may have on the long term stability of repairs for the aircraft, the long term implications for various levels of operating efficiency, etc.

There are any number of generalized performance measures that we may consider. For instance, we may require that the mean square of the deviations of the number of repair records remain within some target value, subject to some fixed number of manhours of support services, specialized services, etc. In short, we would have a quadratic objective function with a set of linear constraints. Or, we could try to confine corrosion rates to a target slope value for the cumulative repair curve, and try to minimize the square of the deviations from it, again subject to some set of constraints (in this example we implicitly assume that low values are as "bad" as high values: consideration of the conditions under which this may be appropriate will be deferred until later). Whatever the choice of objective function and constraint set, a great deal is known about such systems and can be expanded to cover every conceivable aspect of a maintenance operation.

Since state variable theory is to be the main engine relating optimal-control theory, statistical time-series analysis, various programming techniques, and statistical-estimation procedures, it would be well to introduce a few of its main equations. With each of these there is quite a few pages of theoretical development which for the sake of brevity we omit. The general state-variable system we shall consider is:

$$(4)\quad \dot{\underline{M}}(t) = [\underline{E}(t) - \underline{M}(t)]\ C(t) + G(t)U(t)$$

where

$\dot{}$ = the derivative operator
$\_$ = matrix
$\underline{U}(t) = N(0,1)$, input noise (1 x n)
$\underline{G}(t)$ = a (n X n) matrix of scalar values
$\underline{E},\underline{M},\underline{C}$ are defined as before and are (n X n) matrices

Let us now suppose that there is some gain, K(t), to be realized from some policy change. Or suppose that K(t) is some specified target, and we wish to determine the type and amount of chang? in a management policy needed to achieve K(t). Our generalized performance measure is:

$$(5)\quad \min \underline{J}(t) = \mathrm{tr}\ \{\mathrm{var}\ \tilde{\underline{c}}(t)\} = \mathrm{tr}\ \underline{V}_c(t)$$

where

$\tilde{\underline{c}}(t) = \underline{c}(t) - \hat{\underline{c}}(t)$, the difference between actual corrosion and some projected target value
$\underline{V}_c(t)$ = the variance matrix
$\underline{\mathrm{tr}}$ = the trace operator

Skipping quite a bit of material we come to:

$$(6)\quad \dot{\underline{V}}_c(t) = [\underline{E}(t) - \underline{K}(t)\underline{M}(t)]\ \underline{V}_c(t) - \underline{V}_c(t)\ [\underline{E}(t) - \underline{K}(t)\underline{M}'t)]^T + \underline{G}(t)\underline{\Psi}_w(t)\underline{G}^T(t) + \underline{K}(t)\underline{\Psi}_v(t)\underline{K}^T(t)$$

where

$$\Psi(t) = \mathrm{cov}\ \{V(t_1),\ V_2(2)\}$$

From Eq. (6), explicit solutions can be derived, again skipping a good many steps we would have:

$$(7)\ K(t) = V_c(t)M^T(t)\Psi_v^{-1}(t).$$

Thus we would obtain an explicit measure of value of the management policy, M(t), under some rather severe conditions; these being randon-process input, a noise input, and a controller function operating as a compound, quasi-periodic, frequently non-stationary, Poisson process.

The above considerations, and those of the previous pages, form but the merest outline of the steps needed and the problems encountered in forming an overall management-control function.

Subsequent steps in the development of analytical models for management policy would consist of the following: first, plot the trends for numbers of records, numbers of manhours, and flight hours, to see what if any trends exist. This may be done in several ways, such as using a Box-Jenkins technique or visual inspection of the cross-correlation matrix. Second, we may compare the cumulative repair histories of the various aircraft against properties listed for these curves in the Table 41. Where discrepancies are found, appropriate modifications will have to be made on the original assumptions and elsewhere. Third, we might consider modifications of the autoregressive moving-average techniques for estimating parameter values of the underlying process rather than using standard parameter estimation techniques. Fourth, obtain numerical values for the quantities listed in the table and establish regions of confidence for them. Fifth, where an insufficiency

of data is a problem, develop the appropriate simulation techniques to supply the requisite artificial data. Sixth, fully develop the state variable control theory models incorporating the compound, nonstationary, quasi-periodic Poisson process. Seventh, use the models to test various policy options and to forecast corrosion rates.

APPENDIX A

WORK UNIT CODE CORROSION SUMMARY

PCN: 5056B5016 30 June 1973
RCS: LOG-MMO(AR)7179
(Formerly RCS: 16-LOG-K261)

FOREWORD

TITLE: Work Unit Code Corrosion Summary

SOURCE: TO 00-20-2 series, "On" and "Off" equipment work reported on AFTO Form 349.

FREQUENCY: Quarterly (for quarters ending in March, June, September, and December) or not produced at the discretion of the System Manager Air Materiel Area. See AFLCM 66-15.

CONTENTS: This report provides summarized units, manhours, and cost information on components (Work Unit Codes) in selected end pieces of equipment that are experiencing corrosion (how malfunction codes 170 and 667).

USE: Information contained in this report is used to determine the extent of corrosion induced problems on components in accordance with AFLC responsibilities outlined in AFR 400-44.

1. Responsible logistic management organization and end article identification. In the upper left-hand corner of the report, the System Manager Air Materiel Area and end article are identified. Also, the equipment type designator will be shown as well as separate operational areas of special interest, such as aerial delivery systems and AFTAC equipment. Equipment identification will be reflected as follows:

a. For aircraft and related mobile training units, the modified mission symbol (if assigned), basic mission and type symbol, design number, and series (if master record is built for specific series) are specified. For example, F100, T039, T038T, or KC135A. The type designator identifying this equipment printed on the report is "ACF".

b. For air or ground launched missiles, the launch environment symbol, mission symbol, type symbol, design number and series symbol are specified. For example, AIM004A, or LGM030B. The type designator identifying this equipment is "GLM" for ground and "ALM" for air.

c. For ground communications-electronic-meteorological equipment (except L systems), the type, design number, and series

(if the master record is built for a specific series) are specified. For example, FPS020. The type designator identifying this equipment is "CEM".

d. For ground communications L systems, the designation and the equipment classification code are specified. For example, 466L6A1. The type designator identifying this equipment is "CEM".

e. For aircraft engines, the basic engine type and model and the second and third character of the equipment classification code for the aircraft in which the engine is installed are specified. For example, TF033BP. The type designator identifying this equipment is "ENG".

2. Period Ending - This is the last day of the quarter for the data appearing in this report.

3. Data qualifying for entry in this report will be displayed in two separate listings. The first listing will display the 25 high corrosion repair manhour consumer Work Unit Codes in rank order (1 through 25). The second listing will display the balance of the Work Unit Codes that have been reported as being subjected to corrosion repair actions during the quarter. These codes will be arrayed in Work Unit Code sequence but will not include the high 25 codes. Both sequences will have the same data displayed across the page for each Work Unit Code with one exception - the first listing will identify the rank order sequence number.

4. WUC - This column displays the complete five character work unit code (23000, 23100, 23111) as included in the end article B4 master record on which corrosion repair actions have been reported during the quarter.

5. Noun - This column displays the noun(s) describing the work unit codes as listed in the applicable 06 work unit code manual.

6. Month - This column displays a listing of the current month (Mar, Jun, Sep or Dec), prescribing two months and total in which corrosion actions have been reported.

7. Units - These columns display the number of units reported as having corrosion repair accomplished for the current month and the preceding two months against the listed work unit code. Units are listed as the following types:

a. On Eq - On equipment units taken from the AFTO Form 349 containing a how malfunction code of 170 or 667.

b. Off Eq - Off equipment (bench check and shop) units taken from the AFTO Form 349 containing a how malfunction code of 170 or 667.

c. Total - Total units reported on the work unit codes for corrosion repair.

8. Manhours - These columns display the number of manhours (labor hours) reported on corrosion repair on the work unit code for the months listed. Manhours are listed as follows:

a. Sched - Manhours spent as scheduled maintenance and reported by the following Type Maintenance Codes as listed in AFM 300-4, Volume XI:

(1) For Aircraft and Drones (including installed engines, related Mobile Training Sets, and Resident Training Equipment):

Type Maint.	Description
A	Service
C	Basic Postflight or Thruflight Inspection
D	Preflight or Scheduled Inspection
E	Hourly Postflight Inspection or Minor Inspection
H	Home Station Check - Isochronal
J	Calibration of Operational Equipment
M	Interior Refurbishment
P	Periodic, Phased or Major Inspection
R	Depot Maintenance
T	Time Compliance Technical Order

(2) For Air Launched Missiles (including related AGE and Training Equipment):

Type Maint.	Description
A	Service
C	Basic Postflight or Thruflight Inspection
D	Preflight or Scheduled Inspection
E	Hourly Postflight Inspection or Minor Inspection

J	Calibration of Operational Equipment
P	Periodic, Phased or Major Inspection
R	Depot Maintenance
T	Time Compliance Technical Order

(3) For Ground Launched Missiles (including related AGE, Ground C-E-M, and Training Equipment):

Type Maint.	Description
A	Service
D	Scheduled Inspection: Daily, Safety, and Servicing - excludes periodic/phased
F	Scheduled Ground Launched Missile Maintenance - excludes Scheduled Inspections
J	Calibration of Operational Equipment
P	Periodic or Phased Inspection
R	Depot Maintenance
T	Time Compliance Technical Order

(4) For Common AGE (including Peculiar AGE for ACMS Aircraft):

Type Maint.	Description
A	Service
D	Scheduled Inspection
J	Calibration of Operational Equipment
P	Periodic or Phased Inspection
R	Depot Maintenance
T	Time Compliance Technical Order

(5) For Ground C-E-M, COMSEC, and "L" Systems:

Type Maint.	Description
A	Service
D	Scheduled Inspection - Daily/Shift
F	Scheduled Inspection - Phased/Periodic
J	Calibration of Operational Equipment
P	Scheduled Maintenance
R	Depot Maintenance
T	Time Compliance Technical Orders

(6) For Munitions:

Type Maint.	Description
A	Scheduled Maintenance
J	Calibration of Operational Equipment
R	Depot Maintenance
T	Time Compliance Technical Orders

(7) For shop work on removed Engines:

Type Maint.	Description
A	Gas Turbine Engine Scheduled Inspection
C	Gas Turbine Engine Build-up
D	Gas Turbine Engine Teardown
H	Reciprocating Engine Build-up
K	Reciprocating Engine Teardown
Q	Forward Support Spares
R	Depot Maintenance
T	Time Compliance Technical Order

(8) For Class I Trainers:

Type Maint.	Description
A	Service
D	Scheduled Inspection Daily/Safety and Servicing
J	Calibration of Operational Equipment
P	Scheduled Maintenance - Phased/Periodic
R	Depot Maintenance
T	Time Compliance Technical Order

b. Unsched - Manhours spent as unscheduled maintenance and reported by the following Type Maintenance codes as listed in AFM 300-4, Volumn XI.

(1) For Aircraft and Drones:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection
Y	Aircraft Transient Inspection

(2) For Air Launched Missiles:

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Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

(3) For Ground Launched Missiles:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

(4) For Common AGE:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

(5) For Ground C-E-M, COMSEC, and "L" Systems:

Type Maint.	Description
B	Unscheduled Maintenance
H	Emergency On-Site Repair
S	Special Inspection

(6) For Munitions:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

(7) For shop work on removed Engines:

Type Maint.	Description
B	Gas Turbine Engine Intermediate Maintenance (JEIM)
E	Unscheduled Test Cell Operation
L	Reciprocating Engine Field Maintenance
S	Special Inspection
W	Minor Maintenance on Removed Engines
Y	Transient Engine Maintenance

(8) For Class I Trainers:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

c. Total - Total manhours (labor hours) expended on the Work Unit Code for corrosion repair.

9. (Dollars) Cost - This column displays an estimate of the cost to correct the reported corrosion deficiency for the Work Unit Code listed. The figure of $10.83 per manhours is utilized to compute the cost. This is AFLC's current manhour cost which includes overhead.

10. QPA - This column displays the quantity per application (number installed) of the work unit code on the specified end piece of equipment.

11. SEQ - This column displays the rank order of the twenty-five work unit codes contributing the highest dollar cost for corrosion repair based on labor cost only. These sequence numbers will appear only for the work unit code rank order listing (25 WUC maximum).

COMMENTS: All comments regarding the contents, use, and distribution of this report should be submitted through command channels to AFLC/MMOMA, Wright-Patterson AFB OH 45433.

SAAMA
F1 6A ACF

WORK UNIT CODE CORROSION SUMMARY
QUARTER ENDING 73 JUN 30

			---------UNITS---------			---------------MANHOURS---------------			DOLLARS		
WUC	NOUN	MONTH	ON EQ	OFF EQ	TOTAL	SCHED	UNSCH	TOTAL	COST	OPA	SEQ NO.
65AH1*	ANTENNA-IFF 2347	JUN	1		1	604.8	.0	604.8	6,550	001	1
	TOTAL		1		1	604.8	.0	604.8	6,550		
11DCF*	SKIN-ENG INTAKEDUCT	JUN				17.8	.0	17.8	193	008	2
		MAY	7		7	52.4	134.0	186.4	2,019		
		APR				16.6	.0	16.6	180		
	TOTAL		7		7	86.8	134.0	220.8	2,391		
11DEF*	SKIN-ENG INTK DUCT	JUN	4		4	26.0	5.8	31.8	344	008	3
		MAY	3		3	45.0	69.6	114.6	1,241		
		APR				.0	7.0	7.0	76		
	TOTAL		7		7	71.0	82.4	153.4	1,661		
11GAB*	SKIN	JUN	2		2	16.6	16.9	33.5	363	002	4
		MAY	1		1	62.5	.0	62.5	677		
	TOTAL		3		3	79.1	16.9	96.0	1,040		
11DAA*	FRAME	JUN	1		1	88.0	.0	88.0	953	087	5
11DCF*	SKIN-ENG INTKE DUCT	JUN	2		2	35.0	.0	35.0	379	008	6
		APR	2		2	28.2	.0	28.2	305		
	TOTAL		4		4	63.2	.0	63.2	684		
23CCH*	HINGE-DOOR	APR	1		1	52.0	.0	52.0	563	008	7
11DCK*	CORROSION PREV COAT	JUN	1		1	21.3	.0	21.3	231	001	[illegible]
		MAY	1		1	29.4	.0	29.4	318		
	TOTAL		2		2	50.7	.0	50.7	549		
11DDA*	FRAME	JUN	2		2	50.0	.0	50.0	542	005	9
74CA1*	PROGRAMMER 464541	JUN		3	3	4.6	2.3	6.9	75	001	10
		MAY		11	11	24.2	11.1	35.3	382		
	TOTAL			14	14	28.8	13.4	42.2	457		
13AD1*	FITTING-NG TRU SUP	JUN	2		2	38.0	.0	38.0	412	002	11

APPENDIX B

Report of a Visit
to Six Airbases of the
Military Airlift Command

23 August 1976 to 3 September 1976

by

Robert Summitt
Professor and Chairman
Department of Metallurgy, Mechanics, & Materials Science
and
Principal Investigator

Contract No. F 33615-75-C-5284

15 April 1977

Summary

Base Visit

An analysis of C-141A AFM 66-1 data revealed base-to-base variations in corrosion-related repair histories which were not readily explainable in terms of environmental or mission-profile data. Accordingly, a visit was made by Dr. C.T. Lynch (AFML/LLN), SM SGT E. Smith (HQ MAC), and Professor R. Summitt (Michigan State University) between 23 August 1976 and 3 September 1976 to the following MAC airbases: Norton, McChord, Travis, Altus, McGuire, and Charleston. Dover AFB was not included because C-141A aircraft were no longer based there. McConnell AFB was visited to discuss the project with personnel at Boeing-Wichita in connection with possible extension to the B-52 Force, and a short briefing on the trip was presented to BGEN E. Nash at Scott AFB.

Objectives

The objectives of the trip were:

- to interview maintenance personnel at all levels from command to workbench;
- to inspect as many aircraft as practical; and
- to inspect base maintenance facilities.

Information so obtained would help in the identification of factors, other than environment and mission, which produce base variations in the data.

Observations

The major observations of the trip were:

(1) Wide variations exist from base to base in:

- Maintenance practices and policies;

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- maintenance facilities and equipment;
- personnel with respect to numbers, training, and attitude;
- importance attached to corrosion maintenance at command level.

(2) Significant departures from authorized procedures and policies have been made with respect to:

- aircraft maintenance;
- maintenance action reporting; and
- data collection.

(3) Information on maintenance and force utilization practices

- frequently is difficult to obtain;
- often is inaccurate; and
- is not shared effectively (the left-hand not knowing about the right-hand etc.)

Conclusions

These observations, coupled with an exhaustive analysis of AFM 66-1 records, show that significant changes must be made before an effective corrosion tracking and prediction (CTAP) program can be developed from maintenance histories. Two specific areas where changes would be most valuable are:

- Reduce base-to-base variations in maintenance practices and policies. A major step would be a drastic reduction in the volume of documentation personnel at every level are expected to assimilate;
- a major overhaul of AFM 66-1.

An expanded discussion of the 23 August - 3 September 1976 visit and the above items are contained in the following report. A complete discussion of the AFM 66-1

analysis may be found in the Final Report of Contract No. F 33415-75-C-5284, which will be available about 1 November 1977.

Introduction

This report describes a visit to several MAC airbases which was made in order to gather information related to AFM 66-1 maintenance records. An analysis (1) of those records for the C-141A force covering 3Q69 through 2Q75 inclusive had shown that corrosion repair histories were markedly different from one base to another. These differences were not readily explainable in terms of weather, mission, personnel, or any other parameter easily retrieved from Air Force records. Accordingly, it was determined that an on-site visit to six airbases would be of value in further analysis of the data.

This visit was conducted between 24 August 1976 through 1 September 1976. Personnel were: Dr. C.T. Lynch, AFML/LLN, Project Engineer for the Corrosion Prediction program; SM SGT E. Smith, HQ MAC; and Professor R. Summitt, Principal Investigator. An itinerary is shown in Table 1. Objectives of the visit were:

(1) to interview personnel involved in corrosion maintenance at all levels from the repair bench to command;

(2) to inspect as many aircraft as extensively as possible;

(3) to inspect maintenance facilities; and

(4) to determine whether significant manpower variations might exist.

In so far as these objectives were concerned, the visit was very successful. We were received warmly and courteously at every base, and everyone interviewed suffered our questions with almost saintly patience, despite the fact that often-

Table 1. Itinerary

Base	Arrive	Depart
Scott AFB	23 August 76	24 August
Norton	24 August	24 August
McChord	24 August	25 August
Travis	25 August	27 August
Altus	27 August	29 August
McGuire	30 August	31 August
Charleston	31 August	1 September
Scott	1 September	2 September
McConnell	2 September	3 September
Scott	3 September	3 September

times more pressing matters were on their minds. A large volume of information was collected which has been extremely valuable in the continuing analyses of the AFM 66-1 records. A very large measure of credit for this success is due Sgt. Smith, whose experience and knowledge were invaluable.

In terms of corrosion prediction based on AFM 66-1, however, the results were disappointing. The base-to-base variations in all aspects of corrosion maintenance are so large that one must question seriously the value of any force-wide statistical analyses of this data base. The information gained in this series of visits coupled with the related data analyses, however do show clearly the paths which must be taken to improve the data system. Once that has been done, an effective corrosion tracking and prediction program can be developed.

At each airbase visited (except McChord), the visiting team first interviewed the Deputy Chief of Maintenance or a member of his staff in order to explain the purpose of the visit and to obtain an overview of local corrosion maintenance problems. Personnel information was obtained from an appropriate source and then supervisory and maintenance personnel of the FMS corrosion control shop were interviewed.

In these interviews we wanted to learn how the corrosion problem was viewed at each base and what was the local posture toward it.

- Is the environment thought to be severe or mild compared with others?
- Are the facilities and personnel available for corrosion control adequate?
- How much maintenance effort is devoted to corrosion control?
- What is the command-level attitude in this area?

- How would the programs here compare with those at other MAC bases?
- What is the typical mission of this base?
- How are the aircraft used?
- What are the maintenance schedules?
- What features are unique to this base?
- When aircraft are transferred to this base from another, how do they compare with respect to corrosion condition? Are some better?

These and numerous other questions were discussed in great detail and most rewardingly. Following these interviews, the file of AFTO-349 forms, in the corrosion control shop covering about 60 days of maintenance work, were examined to determine whether corrosion work was being reported in accordance with TO 00-20. When discrepancies were found, they were discussed to some extent with the personnel involved.

Next an inspection was made of as many aircraft as practical, usually beginning with those in maintenance docks. Altogether 59 C-141A (and one C-5A) aircraft were inspected. A more-or-less standard inspection procedure was followed, noting condition of the following items:

- paint, upper wing, fuselage, empennage;
- paint, lower surfaces;
- latrine cleanout hatch;
- nose landing gear door;
- skin fasteners, belly, immediately aft of NLG door;
- fasteners, fuselage sides, especially in the region FS 451 to FS 734 and FS 1292 to FS 1558;

- bilges, particularly in the avionics bay;
- thresholds of hatches;
- 25,000 lb. tiedown fittings; and
- interior condition in general.

Maintenance facilities were reviewed, noting the number of docks available, whether specific docks were used for corrosion control, wash racks, availability of hot water, and materials used, e.g., alkaline or solvent-based detergent.

Some problems resulted in a less thorough study than desired at Norton and McChord. Because of itinerary scheduling complications, only half of one day was spent at Norton. Moreover, a Commander's Facilities Inspection (CFI) was scheduled to begin late the same afternoon of our visit, and nearly everyone was preoccupied with preparations. A similar situation was encountered at McChord, where an Operational Readiness Inspection (ORI) was in progress, and both personnel and aircraft simply were not accessible. (Indeed, there were moments when this Kindly Professor - K P - was unsure of his safety under such rigorous security conditions.) As noted previously, however, personnel at both bases did everything possible under difficult (for them) circumstances to accomodate us, and it is to their credit that we were able to acquire as much information as we did. No problems of any sort were encountered at the other bases visited.

Observations

In so far as AFM 66-1 data can be used for force-wide statistical analyses of the corrosion problem, our visit was exceedingly disappointing. From information

obtained during the visits and from further analyses of the data, it is clear that the data base should be likened to the blind men's descriptions of an elephant. The maintenance data histories appear to be unique for each base in terms of what sort of experience is described and how it is described.

A. There are wide variations from one base to another in several important categories.

1. Maintenance practices and policies. The time allowed for isochronal maintenance was found to be from one day to effectively five days during which corrosion maintenance can be accomplished. Obviously the length of time period during which maintenance crews have access to an aircraft will affect the amount of work that can be accomplished.

   The importance attached to corrosion maintenance at management levels apparently is reflected in aircraft painting. At some bases the primary factor in painting policies is the appearance of the aircraft, whereas at others base-level painting is done in a genuine effort to prevent corrosion damage.

2. Maintenance facilities and equipment are quite variable. Wash racks sometimes are indoors, sometimes not. Hot wash water is rare.* Some washing contractors are conscientious and effective, some are not. Water quality may be good or bad (although there is some evidence that the widely known "worst case" of water quality may be beneficial.) At least two different detergents are in use, alkaline and solvent-base. (We noted evidence to suggest that the solvent-base detergent causes damage to various seals on the aircraft.)

   Larger bases have better physical plant facilities, e.g., a separate dock for corrosion control, hence are better equipped to handle maintenance.

3. Personnel. The number of maintenance personnel seems to be tied to the number of aircraft, hence there is a variation in the numbers available to effect repair work. If an effective program is eventually developed to measure the need for repair work, then perhaps a more logical basis will be available to assign personnel to each base, as we have suggested elsewhere (1).

   We found no evidence where the quality of maintenance skills was a problem with the notable exception of painting (see below).

* We understand that, at this date, only Altus and Travis do not have hot wash water.

High turnover rates in personnel at management and bench levels would be expected to cause some difficulties with continuity. One could sense a difference of attitude or enthusiasm with respect to corrosion maintenance from base to base, but it is difficult to pinpoint the cause from such brief observations.

4. The importance attached to corrosion maintenance at management levels was revealed in several ways. Two have been mentioned - the time period allowed for maintenance and the purposes for painting. Another is the case of housekeeping, most of which we understand not to be the responsibility of FMS.

   Although not directly a corrosion condition, certain housekeeping practices can contribute to accelerated corrosion. Specific areas inspected were bilge areas beneathe the avionics bay, general bilges (when accessible), general interior (specifically for standing water and hydraulic fluid), latrine area, and the latrine drain access. With the exception of but one base, conditions in all these areas are bad. Avionics bay bilges frequently held standing water and sometimes raw sewage. Latrine cleanout hatches were nearly always dirty and badly corroded. (Such conditions were the exception at one base, however, proving the areas can be kept clean.) Indeed, it was not uncommon to find latrine clean-out hatches which could not be opened. Latrines were found full and overflowing. Bilges were dirty and frequently wet. Spilled and leaked hydraulic fluid was a common problem (but again, one base tries to control the problem). Standing rainwater from open or leaking hatches was found frequently, especially in the vicinity of rear troop doors. If good housekeeping practices will reduce corrosion damage, then there is much room for improvement.

B. Significant departures from authorized procedures and policies were observed in several areas.

   1. Aircraft maintenance.

   Repainting of aircraft is a routine operation at most bases. Only one base tries to limit its painting to "spot" and touchup as specified in T.O. 1-1-4. Some bases repaint the entire belly in an attempt to control corrosion, others repaint entire aircraft on a regular schedule. In all cases, the effectiveness in corrosion protection seemed marginal, particularly when paint was applied without good surface preparation and corrosion treatment, where needed. Information relating to what paint was used and when applied was not stencilled to the tail of repainted aircraft. Non-standard markings were applied to some.

   The knowledge and skill of painters, as well as the conditions under which painting is done, vary from good to quite bad. It was possible to hand-peel large sheets of finish from some aircraft.

One appeared to have been painted during a sandstorm. Others showed evidence of high quality work with good surface preparation.

Obviously with this state of affairs, it is not possible to evaluate the performance of finishes in preventing corrosion or maintaining appearance. Moreover, it does not seem useful to apply costly finishes, which are claimed to have a six year service life, when (a) their better qualities have not been proved in service through controlled test and (b) they will be overcoated routinely to maintain appearance.

Variations in washing and cleaning have been noted above. Over-enthusiasm can be a problem, however. We observed one aircraft the inside of which had just been hosed down thoroughly, despite express provisions to the contrary (T.O. 1C-141A-23).

2. Maintenance action reporting and data collection practices affect most directly the value of AFM 66-1 for corrosion tracking and prediction. The most serious problem observed was the widespread use of Support General Work Unit Codes for corrosion maintenance. At some bases, only isolated individual workers followed this practice; at others, none did; at some, everyone was guilty. It would appear that a large volume of corrosion work is undocumented outside of the base. The data would be available to base management for a limited time via BLIS, but force-wide maintenance data products, e.g., 16-LOG-K261 "Work Unit Code Corrosion Summary", would suffer from comparing apples with oranges.

   A related problem, not revealed during our visits but by subsequent analyses of the AFM 66-1 data base, is the fact that there is no uniformity of practice in using the various codes. This problem will be described fully in the Final Report of this Project.

   We believe the major source of difficulties in the data system is the overwhelming volume of documentation which personnel at all levels are expected to read and understand. Human nature being what it is, we doubt whether many people do manage to read all of it.

C. Information on maintenance and Force Utilization Practices. Frequently some difficulty was experienced in acquiring information and, in several cases, information was found to be in error. Although everyone made every effort to cooperate with us, the problems of obtaining information are understandable. In some cases we were unable to explain clearly what we wanted to know, and in other cases we were ignorant of the existence of useful data.

Inaccurate information, however, has been a more serious problem. Again, we feel the root cause to be the overwhelming sea of documentation that even the most dedicated people could not master. Several examples will illustrate the sort of problems encountered.

1. Painting. Information from Warner-Robins ALC and AF documents showed that complete aircraft painting is done only at depot or by specific contractors, and field units do nothing but touch up work. Indeed, we were provided detailed histories of painting of the C-141A Force which we expected to use in relating corrosion damage to utilization and preventive measures. But the very first aircraft examined had been completely repainted, except for the stenciled repaint data on the tail (which corresponded with our records.)

2. Inspection cycles. According to FY 1977 and FY 1975 PDM documents (2,3), the inspection cycles in effect are 15 day Home Station Check, 70-day minor inspection, 140 -day major inspection, 36-month mid-interval, and 36-month PDM. In the field, we learned that this cycle had not been in effect for at least two years and a different cycle was in use which seemed to vary slightly from base-to-base.

3. Dedicated Aircraft. It had seemed reasonable to us to assume that specific aircraft would be used for the same mission over extended time periods. Such would be an efficient use of equipment and personnel. Everyone asked insisted nothing of the sort was done, because change of configuration is quite easy. Yet at the next-to-last base visited, we finally acquired information concerning "diplomatic", "courier", and other such dedicated aircraft. They are not dedicated permanently, of course, but the time periods are long enough to have possible effects on corrosion experience.

4. Field MS vs. Organizational MS. Considerable time was spent interviewing FMS corrosion control personnel. We were surprised, when the Owning Work Center codes were compared with AFM 300-4 (see first paragraph under C. above), to learn that not one corrosion record out of 250,000 records in our data base came from these shops. The great bulk of our records had come from OMS.

   Additional examples have been encountered, but those listed are sufficient for this report.

D. Aircraft Condition - Some Additional Observations.

The following comments mostly are concerned with paint failure modes and conditions.

Normal degradation of paint on the upper wing and fuselage results from exposure to ultraviolet radiation. The paint binder decomposes and erodes away leaving exposed pigment particles ("chalk"). Such decomposition is related directly to exposure time and radiation intensity, although wind, sand, and rain may contribute to the erosion rate. In this degradation mode, the film remains intact and continues to protect the underlying metal; the chalky surface is not regarded as attractive, however. Under mild solar conditions, the probable useful lifetime of the polyurethene/epoxy finish system appears to be five to seven years.

Many examples were observed of severe degradation of paint films on the upper surfaces, where the film suffered a loss of integrity and peeled to expose the metal. The worst such cases were found where the solar exposure was highest. This is abnormal film degradation and, if caused by radiation, it suggests that unsuspected problems may exist with the finish systems. A possibly related observation was the general absence of this form of degradation at Altus, where solar exposure is high but the aircraft carry a film of gypsum from the wash water. Paint which degrades in this way probably has a maximum useful life of two or three years.

Paint films fail mechanically because of flexure. This usually occurs on the fuselage, especially forward of the main landing gear pods and in the general area of the cargo deck. Mechanical flexure appears to fracture

the paint around fasteners as well as loosen fasteners and subsequently fracture the film. Seepage of spilled hydraulic fluid past fasteners may play an active role in the process as well as an unsightly passive role. Once fractured, the corrosion of underlying fastener and skin proceeds rapidly.

As noted elsewhere, a variety of repaint cures are attempted: spot painting around individual fasteners; strip painting along lines of fasteners (connect-the-dots); area painting; complete repainting. Close inspection of fasteners in all cases showed that none are effective in stopping the damage. As far as fasteners are concerned, we suspect that all painting efforts are of little value. If the fasteners are at all loose, then it will be but a short time before the film fails again. Clearly the polyurethane/epoxy system is too brittle for this application.

25,000 lb tie down fittings forward of FS1178 appear to have been reworked on all aircraft. Rearward, however, the condition of these TDF's exhibited several degrees of bad. The problem clearly is aggravated by leaving cargo rails installed for extended time periods and by permitting water to enter (through open doors) and to stand in the area. In a number of aircraft at one base, this corrosion was much more severe on the port side, but equally bad on both sides at most bases.

Conclusions

The present Research Program was begun under the assumption that the extent of aircraft corrosion damage, and hence need for repair, could be explained in terms of the environment. The term "environment" was understood in a very

general sense, including the usual environmental factors such as pollution, wind, moisture, operational factors, and miscellaneous factors such as design, accidents, etc. (4). As a result of our exhaustive analysis of AFM 66-1 and mission profile records for the C-141A Force as well as the trip reported herein, we have matured a great deal in our understanding of the word "environment".

Part of the environment very clearly is the individual base posture toward corrosion maintenance. This is a multidimensional problem, but at least one would include these factors: commitment; facilities; data reporting (paperwork). Assigning a "grade" for these categories - plus (+) for good, minus (-) for not-so-good -- for the six MAC bases visited (without naming names) gives the matrix shown in Figure 1.

What is unfortunate, from our viewpoint, is the fact that these three variables (and more) are part of the inputs to AFM 66-1 data. In our data analyses, we have made a great deal of progress toward identifying where and how some of these factors input the data system. Although there is some possibility of filtering them out ("data massage"), it does not at this time seem possible to do this with existing AFM 66-1 records so that they can be converted into an accurate measure of corrosion experience.

AFM 66-1 is in great need of overhaul, if not outright restructuring, from the ground up. It is redundant, superfluous, ponderous, occasionally both relevant and irrelevant. Objectives of this overhaul should be:

- reduce, if not eliminate, base-to-base variations in maintenance policies and practices;
- drastic reduction in the volume of documentation;
- a clear statement of what Force-wide purpose will be achieved via AFM 66-1;
- effective provision for updating the system so that we shall not again

Figure 1

Approximate base ratings on three parameters

	Base A	Base B	Base C	Base D	Base E	Base F	
COMMITMENT	—	+	+	+	+	— ??	
FACILITIES	+	+	—	+	—	—	
DATA REPORTING	—	—	+	—	+	—	

experience the problems we have today.

We assume, of course, that corrosion would be an integral element of a revised AFM 66-1, with sufficient emphasis on accurate reporting to make corrosion tracking and prediction possible.

Acknowledgements

We wish to thank BGEN E. Nash, Col. A.L. Trott, and Col. M.C. Padden, HQ MAC, for their continuing interest in this program. We are especially appreciative for their efforts to make this trip possible and to have SM SGT E. Smith accompany us.

In addition, we wish to express our thanks here to the many people at the various airbases who did so much to help us, with apologies for an occasionally lost first name:

Norton AFB

Lt. Col. K. Lowrey
CM SGT D. Martin
M SGT. J. Whitten

McChord AFB

Mr. C. Mailand
SGT. R. Shippee
Mr. McVittie
Mr. E.A. Richardson

Travis AFB

Lt. Col. C.H. Reese
Mr. T. Kirkpatrick
C. M SGT. Tucker
M SGT. Mongno

Altus AFB

Col. W.G. Holman
Col. J. Ritenour
Lt. Col. Buckner
Major Clemson
Capt. L. Prose
M SGT. Cook
CM SGT. Perala
CM SST. R. Pearson
Mr. Allen

McGuire AFB

Lt. Col. R. Larsen
Mr. C. Kleinfelder
T. SGT. Hacker

Base Visit Report

Charleston AFB

Col. P.L. Geasland
Lt. Col. Harner
Mr. F. Hogan

Mc Connell AFB

Col. R.L. Jones
Col. J. Hampton

Boeing - Wichita

Mr. J. Wherry
Mr. R. Balbierz
Mr. T. Kozan

RS/po'm
4/26/77

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APPENDIX C

MINOR CORROSION HOW-MALFUNCTION CODES, C-141A MAINTENANCE DATA 4Q70 - 4Q74 INCLUSIVE.

Code	No. Records	Description
410	574	Lack of, or improper lubrication
135	318	Binding, stuck or jammed
301	275	Foreign object damage
878	3	Weather damage
037	220	Fluctuates, unstable or erratic
381	129	Leaking - internal or external
800	428	
799	212	No defect
242	69	Failed to operate or function - specific reason unknown
127	35	Adjustment or alignment improper
105	34	Loose or damaged bolts, nuts, screws, rivets, fasteners, clamps or other common hardware
730	27	Loose
932	34	Does not engage, lock or unlock correctly
020	29	Worn, chafed or frayed
160	24	Contacts/connection defective
130	20	Change of value
425	18	Nicked
150	20	Chattering
901	18	Intermittent
804	26	No defect-removed for scheduled maintenance
246	21	Improper or faulty maintenance
910	11	
780	15	Bent, buckled, collapsed, dented, distorted or twisted

Code	No. Records	Description
615	10	Shorted
008	11	Noisy
374	10	Internal failure
750	7	Missing
070	8	Broken
106	8	Missing bolts, nuts, screws, rivets, fasteners, clamps, or other common hardware
330	4	Excessive hum
007	4	Arcing, arced
958	10	Incorrect display
457	3	Oscillating
108	4	Broken, faulty or missing safety wire or key
290	4	Fails diagnostic/automatic test
651	3	Air in system
660	1	Stripped
240	2	?
690	3	Vibration excessive
803	2	No defect-removed for time change
111	2	Burst or ruptured
710	2	Bearing failure or faulty
001	1	G[illegible]y
525	3	Pressure incorrect
567	1	Resistance incorrect
303	2	Bird strike damage
010	1	Poor or incorrect focus
805	1	No defect-not otherwise coded etc. (catchall)

Code	No. Records	Description
080	1	Burned out or defective lamp, meter or indicating device
711	1	Improper blanking
982	1	Frozen tuning mechanism
653	1	Ground speed error excessive
540	1	Punctured
561	1	Unable to adjust to limits
300	1	Grounded electrically
625	1	Gating incorrect
383	2	Lock on malfunction
025	5	Capacitance incorrect
503	2	Sudden stop
177	1	Fuel flow incorrect
255	1	No output/output incorrect
947	1	Torn
720	1	Brush failure/worn excessively
669	1	Potting material melting
900	1	Burned or overheated
167	1	Torque incorrect
812	1	No defects - indicated defect caused by associated equipment malfunction
103	1	Attack display malfunction
935	16	Scored or scratched
602	2	Failed or damaged due to malfunction of associated equipment or item
	2708	

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*U.S.Government Printing Office: 1978 — 757-080/738

AD-A057 984 MICHIGAN STATE UNIV EAST LANSING F/G 1/3
CORROSION TRACKING AND PREDICTION FOR C-141A AIRCRAFT MAINTENAN--ETC(U)
APR 78 R SUMMITT F33615-75-C-5284
UNCLASSIFIED AFML-TR-78-29 NL

3 of 3
AD A057 984

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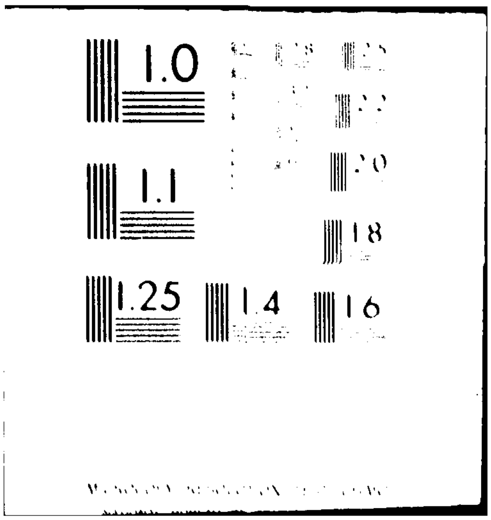
1.0
1.1
1.25
1.4
1.6
1.8

value in predicting corrosion costs. Simpler changes can be effected for this purpose.*

The problems involved are in two general categories: first, the shortcomings of the present management-information system; second, the conditions under which various analytical tools may be employed to eliminate present difficulties and to create a comprehensive management-and policy-planning system. The tools employed will come from a variety of areas, mainly optimal-control theory and time-series analysis. Successful application of these tools would bring the current management reporting effort under control and provide a means of executing long term policy plans. The present system is limited to short-term planning on a local basis, both by design and by the limitations imposed by the current ad hoc collection of data reporting elements. None of these were designed to facilitate comparisons between bases, different operating environments, or different management practices. To achieve such comparisons, it would be necessary to explain fully the observed differences in reported corrosion maintenance rates at the various airbases.

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*One recommended change which should be considered for immediate implementation is a complete editorial revision of Air Force manuals to reduce their volume, and improve their readability and effectiveness. A large library of documentation was accumulated during this study, and it was paralleled by a growing suspicion that little of it ever is read (except, of course, by curious professors). Jablonski (34), in a study for the Air Force, asked "How readable are technical handbooks?" In a survey of AF technicians in Viet Nam, he found "that the use of handbooks was less than we had expected, there was more guessing of information than we'd like to think occurs, and that technicians do not understand technical language even after years of experience." (emphasis added) He laid the blame squarely on the manuals themselves, and showed how to improve them. We can not criticize or improve his recommendations.

Any modeling effort must assume an accurate and viable data reporting system. This assumption has not been fulfilled consistently by MDCS. The difficulties experienced by the Air Force are typical of those encountered in large scale management information systems (35). The present system clearly is the end product of a long evolutionary process. Typically, this means that reports generated frequently will contain nearly identical materials. Much of the information is collected in a fragmentary and incomplete way; each collection effort seems designed to answer some immediate or practical question at some point in the past, but for which no clearcut current use exists.

Examples of such problems may be found in the Work Unit codes, the How-Malfunction codes, and the Action Taken codes. For example, the Work Unit codes provide a general description of the functional part in question. Paralleling this is a system of coordinates describing position (in inches) on the aircraft, referred to as station numbers. The system, however, is two-dimensional, giving coordinates only on surfaces. If one is concerned with a component located in the interior of a wing, for example, the station number system will provide only an approximate location. Further, there are only partial corespondences between the station numbers and the Work Unit codes; that is, only some Work Unit codes are matched to station numbers. Thus, establishing precise locations for many components may not be possible.

If a practical question is asked of the data, such as for a list of corrosion "hot spots", a precise answer can not be

given unless the Work Unit codes were matched previously with the station numbers. Whereas unforeseen design features of the aircraft, particular environmental factors, or corrosion maintenance policies at a given base all may result in corrosion problems in unforeseen areas, we are left without an efficient means of locating them. Problems of this sort create pressures to add more categories to the existing system. Thus, one finds the evolutionary, incomplete and overlapping nature of the MDC system.

These considerations return us to an introductory remark: Who exactly are the information users? What exactly do they need? How much is it going to cost to get that information? Answers to these and other questions could be provided in part by a study of the present codes, with the aim of identifying the users and the effectiveness of the present codes, what revisions are needed, etc. Many of the present codes are used infrequently, if at all. A few codes are used for just about everything. Thus, the large number of code categories and the complex rules for their use are not yielding the discriminatory power intended.

In revising an information system, it is not enough to specify the users, their needs, or the various systems costs. Since we have a complex, interrelated system, trade-offs of various sorts will have to be made among conflicting requirements. Such trade-offs already occur in the present system but not on a basis with any rational foundation, insofar as the overall good of the system is concerned. By way of example

we note that ground crews and other maintenance personnel are required to fill out detailed work forms. Not only does this take time away from the actual work to be performed,* it also interacts with an implicit differential reward system present in the various reporting systems: If detailed work unit specifications are filled out, the airbase receives credit for the work done. In turn, this helps contribute to the size of the next year's budget allocation for additional personnel, support services, etc. However, maintenance personnel can save themselves considerable time by simply writing 02000, general support, on the work order form. Thus, whereas maintenance personnel can free-up a few minutes paperwork-time for every repair, the airbase stands to lose proportionately far more, if such work in not reported correctly. Resolving these difficulties is likely to involve a good deal of effort. We may borrow from Ashby's "law of requisite variety" by noting that complicated systems require complicated methods of description.

Problems do not end here. There is little need to comment on the potential arbitrariness of the How-Malfunction codes. What is "midly corroded" at one airbase may be "severely corroded"

*A major problem relating to corrosion maintenance is the absence of a useful definition for a "unit of work." Unlike the example "removal and reinstallation of an antenna," etc., "corrosion repair" is not defined clearly as to magnitude or difficulty. It might be assumed that manhours of labor would be an effective definition. Unfortunately, the number of records is too large where manhours are indicated as 0.1, i.e., six minutes or less. Since the unit of work is to include the time required to enter data on the AFTO 349, it is clear that the data base contains numerous records where fewer than five minutes were spent on the job.

at another. What is "chipped" in one person's view may be "cracked" in another's.

The most severe problems, however, are found in the Action Taken codes. In their present form, the verbal decision procedures (23) are hopelessly confused, complicated, contradictory, and overlapping. For example, Code F is

> "not to be used to code on-equipment work if another code will apply. When it is used in a shop environment, this code will denote repair as a separate unit of work after a bench check. Shop repair includes total repair manhours and includes cleaning, disassembly, inspection, adjustment, reassembly, and lubrication of minor components incident to the repair when these services are performed by the same work center. For precision measurements equipment, this code will be used only when calibration of the repaired item is required (see code G.)"

Even if maintenance personnel attempted to comply with the conditions imposed on the use of code F, it is difficult to see what useful information would be extracted. These remarks extend to the remaining Action Taken codes. As they currently stand, the Action Taken codes could be scrapped with little loss.

The problems outlined in the previous pages fall into one of three general categories encountered in dealing with management information systems, viz, operational feasibility. Most of the difficulties encountered in the design of such systems are to be found here. There are, however, two other areas, technical feasibility and economic feasibility. Problems associated with the technical feasibility are the easiest to resolve: the technology either is present or not, and if present, the appropriate personnel can get the system running. Traditionally, economic feasibility has been of little direct concern in military operations. Nonetheless, in dealing with

complex systems and competing alternatives among various systems and various reporting requirements, there is considerable room for tests of economic feasibility.

There are a number of elementary considerations and a great many sophisticated considerations that go into reporting system design. All too often it is the elementary considerations that are not given sufficient thought. Among these are the following: first, identify all the reports generated by the computer. How many of these are joint reports?; second, specify the opportunity costs of the system, i.e., what would be the costs if the present system did not exist, or if proposed modifications to it did not occur?; third, where possible, develop formal methods for estimating costs; fourth, are there intangible benefits? If so, what measures will establish their impact? Additional criteria could be added.

The problems mentioned above have limited use of the computer to short-term goals and to largely local-level policy decisions. A reading of the various computer-generated reports listed in AFM 66-1 implies that little more was intended, thus ignoring much of the computer's potential in the management of overall maintenance operations. This need not be the case. Given that the deficiencies in the present codes are corrected, a large variety of analytical tools can be developed and applied to the data.

Behind such tools is a general rationale which attempts to account for the interactions between different airbases, the environmental problems associated with these bases, and the

resulting corrosion rate. The environmental conditions at the various airbases vary widely. There are also differences in maintenance staffing and policy among the various bases. In part, these differences are a response to the wide variance of environmental conditions, and in part they stem from a multitude of factors which render effective control of overall operations difficult.

The cummulative repair history curves of the aircraft stationed at a given base have common characteristics. The various properties of these curves, together with a knowledge of the amount of time spent by these aircraft at different bases, may be used to make inferences about the relative impact of the environmental and managerial factors in operation at the respective bases. The amount of work will depend on the condition of the aircraft upon arrival, and thus upon its previous environmental and management experience. How much work it will receive depends on present management policy and current work loads. The interactions of these effects will determine whether the repair curve will be convex or concave to the orgin. Crudely, if management is "efficient" we would expect, after an initial spate of repairs, that the overall rate would level off to some constant value. On the other hand, if it is not "efficient" we would expect a small pulse, a lag in repairs, and the effects of cumulative corrosion damage to generate an increasing rate of repairs, thus giving rise to a curve concave to the orgin.

Implicit in the above, and in much of what follows, is the idea that the overall corrosion rate is the difference between the environmental impact on the aircraft and the management efforts to compensate that impact. What we can observe is the overall corrosion repair rate. The management and environmental impact on the aircraft and the effects are not directly observable. There are two observable components of management policy: the number of repair records generated and the number of manhours per repair. Assume that environmental effects consist only of two states: mild and severe.

Since we are attempting to analyze the impacts of various policies over time, and the impact of changes in those policies, it is not enough to conduct a time-series analysis of the data. Rather the time-series analysis must be cast in a control-theory format that can handle explicit changes in management policy and delineate the various effects throughout the maintenance operation. This is a formidable task, and it will take several pages to outline the most elementary ideas. However, the range of potential application to the Air Force maintenance operation will be considerable. It will be worthwhile to list a few of these. The mathematical machinery will be sufficient to analyze the effects of, say, various delays (e.g., changes in inspection policy) on the different types of repairs that will occur over time; on the adequacy of various levels of maintenance effort at the different bases; on the overall allocation of resources between different bases, such that some objective function

(say, minimum downtime for aircraft) can be maximum subject to a set of resource constraints. The list can be easily extended.

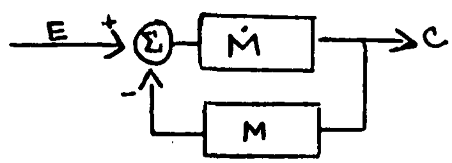
Before proceeding, however, it would be well to go over some basic assumptions. Stated formally our basic assumption is:

(1) $dM/dt = E - M(t) = C(t)$,

where E is the environmentally-induced parts failure-rate due to corrosion (an output)

M is the management effort designed to reduce the impact of E (a controller function), and
C is the corrosion process (an output).

In block diagram form this is:



Typically, the aim is to reduce $dM/dt = \dot{M}$ to zero. However, there are a large number of constraints placed on the controller function, such as insufficient resources, imperfect information, and so forth. There could be situations in which dC/dt is negative, such as when an aircraft shifts from a base characterized by inefficient management and severe environmental conditions to one characterized by efficient management and mild environment. At such a juncture, a lot of "deferred maintenance" may occur, thereby limiting the spread of corrosion; the effect would be a negative slope in dM/dt. But for the most part, we would expect dM/dt to have a positive slope. Different circumstances will dictate whether the slope will be a constant or be some function of time as well.

The direction and slope of the various changes, as well as lags in the various slopes, can be grouped into a number of classifications based on characteristics observable from the cumulative distribution curves of repairs for the aircraft. From these we can make inferences about the underlying relations between the controller function, M, and the environmental impact, E. Upon resorting to various techniques from the theory of optimal control, we should be able to determine the specific forms of the M's for the different bases as well as the impact of the respective E's. Insights into the general problems here are afforded by observing changes in the repair history curves of the various aircraft as they cahnge from base to base.

Two general sets of curves exist: first, those derived from aircraft which have been stationed continuously at one base; second, those which have made transitions between one or more bases. Changes in the latter category will yield changes in M and in E, with attendant effects on dM/dt and in the structure of the response lags. In tabular form, these changes may be classified as follows:

	efficient M_1	not efficient M_2
mild, E_1	a_{11}	a_{12}
severe, E_2	a_{21}	a_{22}

Tentatively, we may classify the different airbases as follows:

a_{11} - Altus

a_{12} - McGuire

a_{21} - Travis, Charleston

a_{22} - McChord, Norton

Some additional comments are in order. First, dM/dt is observable only from the number of manhours, and from the number of records per repair. E and M are not directly observable. Thus, special attention must be given to the over-time relations between records and manhours. Second, we have assumed in Eq. (1) that dM/dt is only a first order difference. However, where corrosion effects become cumulative-as they might in the case of cells a_{12} and especially a_{22} - we also might expect an additional contribution in the form of d^2M/dt^2 so that we would have

(2) $A_2 d^2M/dt^2 + A_1\ dM/dt = E - M(t) = C(t)$.

This would give rise to a quadratic equation of the form

(3) $(A_2 D^2 + A_1 D + 1)\ M=0$,

where D = dM/dt.

Thus, changes in the slopes over time can be plotted in the complex plane to determine the stability of the system (e.g., determine the impact of cumulative corrosion damage caused by various types of maintenance policies, the content and frequency of different inspection procedures, etc.)

We have a clear analogy to a mechanical system. In effect, we attempt to measure an equilibrium position by the strength of the restoring action. The stronger the restoring action, the more stable the system.

The simple system described above assumes, however, a great many properties not existent in the system of concern to us. The above system is deterministic and continuous. Our system is neither. It is discrete and probabilistic. For the present, however, little will be lost by continuing to assume continuity. When appropriate, we can make the modifications necessary to effect a discrete sampled data system.

The majority of the complications arise from the assumption that events are probabilistic rather than deterministic. The cumulative repair history curve is a quasi-periodic, compound, stochastic, Poisson process; that is repairs can occur at any time, in any amount, but mostly according to stated intervals for the various types of inspections. Because of changes in base assignment and management-efficiency levels, the probability density and moment-generating functions cannot be assumed to be constant over time, or stationary. Traditional treatment of Poisson processes assumes that only "one" repair can occur in any arbitrarily small unit of time, and that the time of occurrence is random according to an exponential probability distribution (one consequence of using this assumption when it is not valid is an overabundance of stock levels). (34)

Even with the above complications taken into account, there are still some general properties common to the cumulative repair histories when they are classified according to changes in the cells a_{ij}. These are listed in Table 41.

In dealing with actual groups of aircraft and the numerous properties of their respective repair curves, we shall be

TABLE 41. PROPERTIES OF CUMMULATIVE REPAIR HISTORIES

Range	dC/dt before	dC/dt after	initial lag size	change in lag size	curve shape	mean value after	variance after	auto-correlation	auto-covariance	order (1 or 2)	type of stationary
a_{11}	K_1	-	τ_1	-	cv	μ_1	σ_1^2	dec	$\gamma(\tau)$	1	ss
a_{21}	K_2	-	τ_2	-	cv	μ_2	σ_2^2	dec	$\gamma(t)$	1	ss
a_{12}	K_3	-	τ_3	-	cc	μ_3	$t\sigma_3^2$	inc	$\gamma(t)$	2	ws
a_{22}	K_4t	-	τ_4	-	cc	μ_t	$t\sigma_4^2$	inc	$\gamma(t,\tau)$	2	ns
$a_{11}\to a_{21}$	K_1	K_2	τ_1	$\tau_2-\tau_1$	cv	μ	σ_2^2	dec	$\gamma(t)$	1	ss
$\to a_{12}$	K_1	K_3	τ_1	$\tau_3-\tau_1$	cc	μ	$t\sigma^2$	inc	$\gamma(t,\tau)$	2	ws
$\to a_{22}$	K_1	K_4t	τ_1	$\tau_4-\tau_1$	cc	μ_t	$t\sigma^2$	inc	$\gamma(t)$	2	ns
$a_{21}\to a_{11}$	K_2	K_1	τ_2	$\tau_2-\tau_1$	cv	μ	σ^2	dec	$\gamma(\tau)$	1	ss
$\to a_{12}$	K_2	K_3	τ_2	$\tau_3-\tau_2$	cc	μ	$t\sigma^2$	inc	$\gamma(t,\tau)$	2	ws
$\to a_{22}$	K_2	K_4t	τ_2	$\tau_4-\tau_2$	cc	μ_t	$t\sigma^2$	inc	$\gamma(t)$	2	ns
$a_{12}\to a_{11}$	K_3	K_1	τ_3	$\tau_1-\tau_3$	cv	μ	σ^2	dec	$\gamma(t)$	1	ss
$\to a_{21}$	K_3	K_2	τ_3	$\tau_2-\tau_3$	cv	μ	σ^2	dec	$\gamma(t,\tau)$	1	ss
$\to a_{22}$	K_3	K_4t	τ_3	$\tau_4-\tau_3$	cc	μ_t	$t\sigma^2$	inc	$\gamma(t)$	2	ns
$a_{22}\to a_{11}$	K_4t	K_1	τ_4	$\tau_1-\tau_4$	cv	μ	σ^2	dec	$\gamma(\tau)$	1	ss
$\to a_{21}$	K_4t	K_2	τ_4	$\tau_2-\tau_4$	cv	μ	σ^2	dec	$\gamma(\tau)$	1	ss
$\to a_{12}$	K_4t	K_3	τ_4	$\tau_3-\tau_4$	cc	μ_t	$t\sigma^2$	inc	$\gamma(\tau)$	2	ws

Inequalities;

$0=K_1<K_2<K_3<K_4$

$0=\tau_1<\tau_2<\tau_3<\tau_4$

matrix

	M_1	M_2
E_1	a_{11}	a_{12}
E_2	a_{21}	a_{22}

(autocovariance is either a function of or both 't' and τ)

Abbreviations;

cc=concave
cv=convex
ns=not stationary
ss=strict sense stationary
ws=wide sense stationary
sk=stationary, order k, k=1,2,3,...
t=time

dec=decreasing (damp out quickly)
inc=increasing (fail to damp out quickly)

definitions;

mean value $\mu x = \Sigma x_i/N$

variance $\gamma\sim\ - E\ [\{Xt - \mu(t)\}^2]$

auto-covariance $\gamma\tau = E\{[Xt - \mu(t)]\ [X\tau - \gamma(t+\tau)]\} = \text{cov}\ [Xt_1\ X\tau]$

autocorrelation $\rho\tau = \gamma\tau/\gamma o = \dfrac{\gamma xx(t_1, t\sim)}{\sigma(t_1)\sigma(t_2)}$

required to introduce matrix notation. This will require the introduction of state variable theory. Since there is a practical payoff, such a procedure should not be viewed as another unmitigated abstraction. Rather, it will enable us to use several new performance measures each as the autocovariance, autocorrelation, and cross-correlation matrices. The damping rates of these functions may be used to determine the stationarity of a series, what effects changes in lags may have on the long term stability of repairs for the aircraft, the long term implications for various levels of operating efficiency, etc.

There are any number of generalized performance measures that we may consider. For instance, we may require that the mean square of the deviations of the number of repair records remain within some target value, subject to some fixed number of manhours of support services, specialized services, etc. In short, we would have a quadratic objective function with a set of linear constraints. Or, we could try to confine corrosion rates to a target slope value for the cumulative repair curve, and try to minimize the square of the deviations from it, again subject to some set of constraints (in this example we implicitly assume that low values are as "bad" as high values: consideration of the conditions under which this may be appropriate will be deferred until later). Whatever the choice of objective function and constraint set, a great deal is known about such systems and can be expanded to cover every conceivable aspect of a maintenance operation.

Since state variable theory is to be the main engine relating optimal-control theory, statistical time-series analysis, various programming techniques, and statistical-estimation procedures, it would be well to introduce a few of its main equations. With each of these there is quite a few pages of theoretical development which for the sake of brevity we omit. The general state-variable system we shall consider is:

$$(4)\quad \dot{\underline{M}}(t) = [\underline{E}(t) - \underline{M}(t)]\ C(t) + G(t)U(t)$$

where

$\dot{}$ = the derivative operator
$\underline{\ }$ = matrix
$\underline{U}(t) = N(0,1)$, input noise (1 x n)
$\underline{G}(t)$ = a (n X n) matrix of scalar values
$\underline{E},\underline{M},\underline{C}$ are defined as before and are (n X n) matrices

Let us now suppose that there is some gain, K(t), to be realized from some policy change. Or suppose that K(t) is some specified target, and we wish to determine the type and amount of change in a management policy needed to achieve K(t). Our generalized performance measure is:

$$(5)\quad \min \underline{J}(t) = \mathrm{tr}\ \{\mathrm{var}\ \underline{\tilde{c}}(t)\} = \mathrm{tr}\ \underline{V}_c(t)$$

where

$\underline{\tilde{c}}(t) = \underline{c}(t) - \underline{\hat{c}}(t)$, the difference between actual corrosion and some projected target value
$\underline{V}_c(t)$ = the variance matrix
tr = the trace operator

Skipping quite a bit of material we come to:

$$(6)\quad \dot{\underline{V}}_c(t) = [\underline{E}(t) - \underline{K}(t)\underline{M}(t)]\ \underline{V}_c(t) - \underline{V}_c(t)\ [\underline{E}(t) - \underline{K}(t)\underline{M}(t)]^T + \underline{G}(t)\underline{\Psi}_w(t)\underline{G}^T(t) + \underline{K}(t)\underline{\Psi}_v(t)\underline{K}^T(t)$$

where

$$\Psi(t) = \mathrm{cov}\ \{V(t_1),\ V_2(2)\}$$

From Eq. (6), explicit solutions can be derived, again skipping a good many steps we would have:

$$(7)\quad K(t) = V_c(t)M^T(t)\Psi_v^{-1}(t).$$

Thus we would obtain an explicit measure of value of the management policy, M(t), under some rather severe conditions; these being randon-process input, a noise input, and a controller function operating as a compound, quasi-periodic, frequently non-stationary, Poisson process.

The above considerations, and those of the previous pages, form but the merest outline of the steps needed and the problems encountered in forming an overall management-control function.

Subsequent steps in the development of analytical models for management policy would consist of the following: first, plot the trends for numbers of records, numbers of manhours, and flight hours, to see what if any trends exist. This may be done in several ways, such as using a Box-Jenkins technique or visual inspection of the cross-correlation matrix. Second, we may compare the cumulative repair histories of the various aircraft against properties listed for these curves in the Table 41. Where discrepancies are found, appropriate modifications will have to be made on the original assumptions and elsewhere. Third, we might consider modifications of the autoregressive moving-average techniques for estimating parameter values of the underlying process rather than using standard parameter estimation techniques. Fourth, obtain numerical values for the quantities listed in the table and establish regions of confidence for them. Fifth, where an insufficiency

of data is a problem, develop the appropriate simulation techniques to supply the requisite artificial data. Sixth, fully develop the state variable control theory models incorporating the compound, nonstationary, quasi-periodic Poisson process. Seventh, use the models to test various policy options and to forecast corrosion rates.

APPENDIX A

WORK UNIT CODE CORROSION SUMMARY

PCN: 5056B5016 30 June 1973
RCS: LOG-MMO(AR)7179
(Formerly RCS: 16-LOG-K261)

FOREWORD

TITLE: Work Unit Code Corrosion Summary

SOURCE: TO 00-20-2 series, "On" and "Off" equipment work reported on AFTO Form 349.

FREQUENCY: Quarterly (for quarters ending in March, June, September, and December) or not produced at the discretion of the System Manager Air Materiel Area. See AFLCM 66-15.

CONTENTS: This report provides summarized units, manhours, and cost information on components (Work Unit Codes) in selected end pieces of equipment that are experiencing corrosion (how malfunction codes 170 and 667).

USE: Information contained in this report is used to determine the extent of corrosion induced problems on components in accordance with AFLC responsibilities outlined in AFR 400-44.

1. Responsible logistic management organization and end article identification. In the upper left-hand corner of the report, the System Manager Air Materiel Area and end article are identified. Also, the equipment type designator will be shown as well as separate operational areas of special interest, such as aerial delivery systems and AFTAC equipment. Equipment identification will be reflected as follows:

a. For aircraft and related mobile training units, the modified mission symbol (if assigned), basic mission and type symbol, design number, and series (if master record is built for specific series) are specified. For example, F100, T039, T038T, or KC135A. The type designator identifying this equipment printed on the report is "ACF".

b. For air or ground launched missiles, the launch environment symbol, mission symbol, type symbol, design number and series symbol are specified. For example, AIM004A, or LGM030B. The type designator identifying this equipment is "GLM" for ground and "ALM" for air.

c. For ground communications-electronic-meteorological equipment (except L systems), the type, design number, and series

(if the master record is built for a specific series) are specified. For example, FPS020. The type designator identifying this equipment is "CEM".

d. For ground communications L systems, the designation and the equipment classification code are specified. For example, 466L6A1. The type designator identifying this equipment is "CEM".

e. For aircraft engines, the basic engine type and model and the second and third character of the equipment classification code for the aircraft in which the engine is installed are specified. For example, TF033BP. The type designator identifying this equipment is "ENG".

2. Period Ending - This is the last day of the quarter for the data appearing in this report.

3. Data qualifying for entry in this report will be displayed in two separate listings. The first listing will display the 25 high corrosion repair manhour consumer Work Unit Codes in rank order (1 through 25). The second listing will display the balance of the Work Unit Codes that have been reported as being subjected to corrosion repair actions during the quarter. These codes will be arrayed in Work Unit Code sequence but will not include the high 25 codes. Both sequences will have the same data displayed across the page for each Work Unit Code with one exception - the first listing will identify the rank order sequence number.

4. WUC - This column displays the complete five character work unit code (23000, 23100, 23111) as included in the end article B4 master record on which corrosion repair actions have been reported during the quarter.

5. Noun - This column displays the noun(s) describing the work unit codes as listed in the applicable 06 work unit code manual.

6. Month - This column displays a listing of the current month (Mar, Jun, Sep or Dec), prescribing two months and total in which corrosion actions have been reported.

7. Units - These columns display the number of units reported as having corrosion repair accomplished for the current month and the preceding two months against the listed work unit code. Units are listed as the following types:

a. On Eq - On equipment units taken from the AFTO Form 349 containing a how malfunction code of 170 or 667.

b. Off Eq - Off equipment (bench check and shop) units taken from the AFTO Form 349 containing a how malfunction code of 170 or 667.

c. Total - Total units reported on the work unit codes for corrosion repair.

8. Manhours - These columns display the number of manhours (labor hours) reported on corrosion repair on the work unit code for the months listed. Manhours are listed as follows:

a. Sched - Manhours spent as scheduled maintenance and reported by the following Type Maintenance Codes as listed in AFM 300-4, Volume XI:

(1) For Aircraft and Drones (including installed engines, related Mobile Training Sets, and Resident Training Equipment):

Type Maint.	Description
A	Service
C	Basic Postflight or Thruflight Inspection
D	Preflight or Scheduled Inspection
E	Hourly Postflight Inspection or Minor Inspection
H	Home Station Check - Isochronal
J	Calibration of Operational Equipment
M	Interior Refurbishment
P	Periodic, Phased or Major Inspection
R	Depot Maintenance
T	Time Compliance Technical Order

(2) For Air Launched Missiles (including related AGE and Training Equipment):

Type Maint.	Description
A	Service
C	Basic Postflight or Thruflight Inspection
D	Preflight or Scheduled Inspection
E	Hourly Postflight Inspection or Minor Inspection

J	Calibration of Operational Equipment
P	Periodic, Phased or Major Inspection
R	Depot Maintenance
T	Time Compliance Technical Order

(3) For Ground Launched Missiles (including related AGE, Ground C-E-M, and Training Equipment):

Type Maint.	Description
A	Service
D	Scheduled Inspection: Daily, Safety, and Servicing - excludes periodic/phased
F	Scheduled Ground Launched Missile Maintenance - excludes Scheduled Inspections
J	Calibration of Operational Equipment
P	Periodic or Phased Inspection
R	Depot Maintenance
T	Time Compliance Technical Order

(4) For Common AGE (including Peculiar AGE for ACMS Aircraft):

Type Maint.	Description
A	Service
D	Scheduled Inspection
J	Calibration of Operational Equipment
P	Periodic or Phased Inspection
R	Depot Maintenance
T	Time Compliance Technical Order

(5) For Ground C-E-M, COMSEC, and "L" Systems:

Type Maint.	Description
A	Service
D	Scheduled Inspection - Daily/Shift
F	Scheduled Inspection - Phased/Periodic
J	Calibration of Operational Equipment
P	Scheduled Maintenance
R	Depot Maintenance
T	Time Compliance Technical Orders

(6) For Munitions:

Type Maint.	Description
A	Scheduled Maintenance
J	Calibration of Operational Equipment
R	Depot Maintenance
T	Time Compliance Technical Orders

(7) For shop work on removed Engines:

Type Maint.	Description
A	Gas Turbine Engine Scheduled Inspection
C	Gas Turbine Engine Build-up
D	Gas Turbine Engine Teardown
H	Reciprocating Engine Build-up
K	Reciprocating Engine Teardown
Q	Forward Support Spares
R	Depot Maintenance
T	Time Compliance Technical Order

(8) For Class I Trainers:

Type Maint.	Description
A	Service
D	Scheduled Inspection Daily/Safety and Servicing
J	Calibration of Operational Equipment
P	Scheduled Maintenance - Phased/Periodic
R	Depot Maintenance
T	Time Compliance Technical Order

b. Unsched - Manhours spent as unscheduled maintenance and reported by the following Type Maintenance codes as listed in AFM 300-4, Volumn XI.

(1) For Aircraft and Drones:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection
Y	Aircraft Transient Inspection

(2) For Air Launched Missiles:

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Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

(3) For Ground Launched Missiles:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

(4) For Common AGE:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

(5) For Ground C-E-M, COMSEC, and "L" Systems:

Type Maint.	Description
B	Unscheduled Maintenance
H	Emergency On-Site Repair
S	Special Inspection

(6) For Munitions:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

(7) For shop work on removed Engines:

Type Maint.	Description
B	Gas Turbine Engine Intermediate Maintenance (JEIM)
E	Unscheduled Test Cell Operation
L	Reciprocating Engine Field Maintenance
S	Special Inspection
W	Minor Maintenance on Removed Engines
Y	Transient Engine Maintenance

(8) For Class I Trainers:

Type Maint.	Description
B	Unscheduled Maintenance
S	Special Inspection

c. Total - Total manhours (labor hours) expended on the Work Unit Code for corrosion repair.

9. (Dollars) Cost - This column displays an estimate of the cost to correct the reported corrosion deficiency for the Work Unit Code listed. The figure of $10.83 per manhours is utilized to compute the cost. This is AFLC's current manhour cost which includes overhead.

10. QPA - This column displays the quantity per application (number installed) of the work unit code on the specified end piece of equipment.

11. SEQ - This column displays the rank order of the twenty-five work unit codes contributing the highest dollar cost for corrosion repair based on labor cost only. These sequence numbers will appear only for the work unit code rank order listing (25 WUC maximum).

COMMENTS: All comments regarding the contents, use, and distribution of this report should be submitted through command channels to AFLC/MMOMA, Wright-Patterson AFB OH 45433.

SAAMA
F1 6A ACF

WORK UNIT CODE CORROSION SUMMARY
QUARTER ENDING 73 JUN 30

WUC	NOUN	MONTH	UNITS ON EQ	UNITS OFF EQ	UNITS TOTAL	MANHOURS SCHED	MANHOURS UNSCH	MANHOURS TOTAL	DOLLARS COST	OPA	SEQ NO.
65AH1•	ANTENNA-IFF 2347	JUN	1		1	604.8	.0	604.8	6,550	001	1
	TOTAL		1		1	604.8	.0	604.8	6,550		
11DCF•	SKIN-ENG INTAKEDUCT	JUN				17.8	.0	17.8	193	008	2
		MAY	7		7	52.4	134.0	186.4	2,019		
		APR				16.6	.0	16.6	180		
	TOTAL		7		7	86.8	134.0	220.8	2,391		
11DEF•	SKIN-ENG INTK DUCT	JUN	4		4	26.0	5.8	31.8	344	008	3
		MAY	3		3	45.0	69.6	114.6	1,241		
		APR				.0	7.0	7.0	76		
	TOTAL		7		7	71.0	82.4	153.4	1,661		
11GAB•	SKIN	JUN	2		2	16.6	16.9	33.5	363	002	4
		MAY	1		1	62.5	.0	62.5	677		
	TOTAL		3		3	79.1	16.9	96.0	1,040		
11DAA•	FRAME	JUN	1		1	88.0	.0	88.0	953	087	5
11DCF•	SKIN-ENG INTKE DUCT	JUN	2		2	35.0	.0	35.0	379	008	6
		APR	2		2	28.2	.0	28.2	305		
	TOTAL		4		4	63.2	.0	63.2	684		
23CCW•	HINGE-DOOR	APR	1		1	52.0	.0	52.0	563	008	7
11DCK•	CORROSION PREV COAT	JUN	1		1	21.3	.0	21.3	231	001	[illegible]
		MAY	1		1	29.4	.0	29.4	318		
	TOTAL		2		2	50.7	.0	50.7	549		
11DDA•	FRAME	JUN	2		2	50.0	.0	50.0	542	005	9
74CA1•	PROGRAMMER 464541	JUN		3	3	4.6	2.3	6.9	75	001	10
		MAY		11	11	24.2	11.1	35.3	382		
	TOTAL			14	14	28.8	13.4	42.2	457		
13AD1•	FITTING-NG TRU SUP	JUN	2		2	38.0	.0	38.0	412	002	11

APPENDIX B

Report of a Visit to Six Airbases of the Military Airlift Command

23 August 1976 to 3 September 1976

by

Robert Summitt
Professor and Chairman
Department of Metallurgy, Mechanics, & Materials Science
and
Principal Investigator

Contract No. F 33615-75-C-5284

15 April 1977

Summary

Base Visit

An analysis of C-141A AFM 66-1 data revealed base-to-base variations in corrosion-related repair histories which were not readily explainable in terms of environmental or mission-profile data. Accordingly, a visit was made by Dr. C.T. Lynch (AFML/LLN), SM SGT E. Smith (HQ MAC), and Professor R. Summitt (Michigan State University) between 23 August 1976 and 3 September 1976 to the following MAC airbases: Norton, McChord, Travis, Altus, McGuire, and Charleston. Dover AFB was not included because C-141A aircraft were no longer based there. McConnell AFB was visited to discuss the project with personnel at Boeing-Wichita in connection with possible extension to the B-52 Force, and a short briefing on the trip was presented to BGEN E. Nash at Scott AFB.

Objectives

The objectives of the trip were:

- to interview maintenance personnel at all levels from command to workbench;
- to inspect as many aircraft as practical; and
- to inspect base maintenance facilities.

Information so obtained would help in the identification of factors, other than environment and mission, which produce base variations in the data.

Observations

The major observations of the trip were:

(1) Wide variations exist from base to base in:

- Maintenance practices and policies;

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- maintenance facilities and equipment;
- personnel with respect to numbers, training, and attitude;
- importance attached to corrosion maintenance at command level.

(2) Significant departures from authorized procedures and policies have been made with respect to:

- aircraft maintenance;
- maintenance action reporting; and
- data collection.

(3) Information on maintenance and force utilization practices

- frequently is difficult to obtain;
- often is inaccurate; and
- is not shared effectively (the left-hand not knowing about the right-hand etc.)

Conclusions

These observations, coupled with an exhaustive analysis of AFM 66-1 records, show that significant changes must be made before an effective corrosion tracking and prediction (CTAP) program can be developed from maintenance histories. Two specific areas where changes would be most valuable are:

- Reduce base-to-base variations in maintenance practices and policies. A major step would be a drastic reduction in the volume of documentation personnel at every level are expected to assimilate;
- a major overhaul of AFM 66-1.

An expanded discussion of the 23 August - 3 September 1976 visit and the above items are contained in the following report. A complete discussion of the AFM 66-1

analysis may be found in the Final Report of Contract No. F 33415-75-C-5284, which will be available about 1 November 1977.

Introduction

This report describes a visit to several MAC airbases which was made in order to gather information related to AFM 66-1 maintenance records. An analysis (1) of those records for the C-141A force covering 3Q69 through 2Q75 inclusive had shown that corrosion repair histories were markedly different from one base to another. These differences were not readily explainable in terms of weather, mission, personnel, or any other parameter easily retrieved from Air Force records. Accordingly, it was determined that an on-site visit to six airbases would be of value in further analysis of the data.

This visit was conducted between 24 August 1976 through 1 September 1976. Personnel were: Dr. C.T. Lynch, AFML/LLN, Project Engineer for the Corrosion Prediction program; SM SGT E. Smith, HQ MAC; and Professor R. Summitt, Principal Investigator. An itinerary is shown in Table 1. Objectives of the visit were:

(1) to interview personnel involved in corrosion maintenance at all levels from the repair bench to command;

(2) to inspect as many aircraft as extensively as possible;

(3) to inspect maintenance facilities; and

(4) to determine whether significant manpower variations might exist.

In so far as these objectives were concerned, the visit was very successful. We were received warmly and courteously at every base, and everyone interviewed suffered our questions with almost saintly patience, despite the fact that often-

Table 1. Itinerary

Base	Arrive	Depart
Scott AFB	23 August 76	24 August
Norton	24 August	24 August
McChord	24 August	25 August
Travis	25 August	27 August
Altus	27 August	29 August
McGuire	30 August	31 August
Charleston	31 August	1 September
Scott	1 September	2 September
McConnell	2 September	3 September
Scott	3 September	3 September

times more pressing matters were on their minds. A large volume of information was collected which has been extremely valuable in the continuing analyses of the AFM 66-1 records. A very large measure of credit for this success is due Sgt. Smith, whose experience and knowledge were invaluable.

In terms of corrosion prediction based on AFM 66-1, however, the results were disappointing. The base-to-base variations in all aspects of corrosion maintenance are so large that one must question seriously the value of <u>any</u> force-wide statistical analyses of this data base. The information gained in this series of visits coupled with the related data analyses, however do show clearly the paths which must be taken to improve the data system. Once that has been done, an effective corrosion tracking and prediction program can be developed.

At each airbase visited (except McChord), the visiting team first interviewed the Deputy Chief of Maintenance or a member of his staff in order to explain the purpose of the visit and to obtain an overview of local corrosion maintenance problems. Personnel information was obtained from an appropriate source and then supervisory and maintenance personnel of the FMS corrosion control shop were interviewed.

In these interviews we wanted to learn how the corrosion problem was viewed at each base and what was the local posture toward it.

- Is the environment thought to be severe or mild compared with others?
- Are the facilities and personnel available for corrosion control adequate?
- How much maintenance effort is devoted to corrosion control?
- What is the command-level attitude in this area?

- How would the programs here compare with those at other MAC bases?
- What is the typical mission of this base?
- How are the aircraft used?
- What are the maintenance schedules?
- What features are unique to this base?
- When aircraft are transferred to this base from another, how do they compare with respect to corrosion condition? Are some better?

These and numerous other questions were discussed in great detail and most rewardingly. Following these interviews, the file of AFTO-349 forms, in the corrosion control shop covering about 60 days of maintenance work, were examined to determine whether corrosion work was being reported in accordance with TO 00-20. When discrepancies were found, they were discussed to some extent with the personnel involved.

Next an inspection was made of as many aircraft as practical, usually beginning with those in maintenance docks. Altogether 59 C-141A (and one C-5A) aircraft were inspected. A more-or-less standard inspection procedure was followed, noting condition of the following items:

- paint, upper wing, fuselage, empennage;
- paint, lower surfaces;
- latrine cleanout hatch;
- nose landing gear door;
- skin fasteners, belly, immediately aft of NLG door;
- fasteners, fuselage sides, especially in the region FS 451 to FS 734 and FS 1292 to FS 1558;

- bilges, particularly in the avionics bay;
- thresholds of hatches;
- 25,000 lb. tiedown fittings; and
- interior condition in general.

Maintenance facilities were reviewed, noting the number of docks available, whether specific docks were used for corrosion control, wash racks, availability of hot water, and materials used, e.g., alkaline or solvent-based detergent.

Some problems resulted in a less thorough study than desired at Norton and McChord. Because of itinerary scheduling complications, only half of one day was spent at Norton. Moreover, a Commander's Facilities Inspection (CFI) was scheduled to begin late the same afternoon of our visit, and nearly everyone was preoccupied with preparations. A similar situation was encountered at McChord, where an Operational Readiness Inspection (ORI) was in progress, and both personnel and aircraft simply were not accessible. (Indeed, there were moments when this Kindly Professor - K P - was unsure of his safety under such rigorous security conditions.) As noted previously, however, personnel at both bases did everything possible under difficult (for them) circumstances to accomodate us, and it is to their credit that we were able to acquire as much information as we did. No problems of any sort were encountered at the other bases visited.

Observations

In so far as AFM 66-1 data can be used for force-wide statistical analyses of the corrosion problem, our visit was exceedingly disappointing. From information

obtained during the visits and from further analyses of the data, it is clear that the data base should be likened to the blind men's descriptions of an elephant. The maintenance data histories appear to be unique for each base in terms of what sort of experience is described and how it is described.

A. There are wide variations from one base to another in several important categories.

1. Maintenance practices and policies. The time allowed for isochronal maintenance was found to be from one day to effectively five days during which corrosion maintenance can be accomplished. Obviously the length of time period during which maintenance crews have access to an aircraft will affect the amount of work that can be accomplished.

   The importance attached to corrosion maintenance at management levels apparently is reflected in aircraft painting. At some bases the primary factor in painting policies is the appearance of the aircraft, whereas at others base-level painting is done in a genuine effort to prevent corrosion damage.

2. Maintenance facilities and equipment are quite variable. Wash racks sometimes are indoors, sometimes not. Hot wash water is rare.* Some washing contractors are conscientious and effective, some are not. Water quality may be good or bad (although there is some evidence that the widely known "worst case" of water quality may be beneficial.) At least two different detergents are in use, alkaline and solvent-base. (We noted evidence to suggest that the solvent-base detergent causes damage to various seals on the aircraft.)

   Larger bases have better physical plant facilities, e.g., a separate dock for corrosion control, hence are better equipped to handle maintenance.

3. Personnel. The number of maintenance personnel seems to be tied to the number of aircraft, hence there is a variation in the numbers available to effect repair work. If an effective program is eventually developed to measure the <u>need</u> for repair work, then perhaps a more logical basis will be available to assign personnel to each base, as we have suggested elsewhere (1).

   We found no evidence where the quality of maintenance skills was a problem with the notable exception of painting (see below).

* We understand that, at this date, only Altus and Travis do not have hot wash water.

High turnover rates in personnel at management and bench levels would be expected to cause some difficulties with continuity. One could sense a difference of attitude or enthusiasm with respect to corrosion maintenance from base to base, but it is difficult to pinpoint the cause from such brief observations.

4. The importance attached to corrosion maintenance at management levels was revealed in several ways. Two have been mentioned - the time period allowed for maintenance and the purposes for painting. Another is the case of housekeeping, most of which we understand not to be the responsibility of FMS.

   Although not directly a corrosion condition, certain housekeeping practices can contribute to accelerated corrosion. Specific areas inspected were bilge areas beneathe the avionics bay, general bilges (when accessible), general interior (specifically for standing water and hydraulic fluid), latrine area, and the latrine drain access. With the exception of but one base, conditions in all these areas are bad. Avionics bay bilges frequently held standing water and sometimes raw sewage. Latrine cleanout hatches were nearly always dirty and badly corroded. (Such conditions were the exception at one base, however, proving the areas can be kept clean.) Indeed, it was not uncommon to find latrine cleanout hatches which could not be opened. Latrines were found full and overflowing. Bilges were dirty and frequently wet. Spilled and leaked hydraulic fluid was a common problem (but again, one base tries to control the problem). Standing rainwater from open or leaking hatches was found frequently, especially in the vicinity of rear troop doors. If good housekeeping practices will reduce corrosion damage, then there is much room for improvement.

B. Significant departures from authorized procedures and policies were observed in several areas.

   1. Aircraft maintenance.

      Repainting of aircraft is a routine operation at most bases. Only one base tries to limit its painting to "spot" and touchup as specified in T.O. 1-1-4. Some bases repaint the entire belly in an attempt to control corrosion, others repaint entire aircraft on a regular schedule. In all cases, the effectiveness in corrosion protection seemed marginal, particularly when paint was applied without good surface preparation and corrosion treatment, where needed. Information relating to what paint was used and when applied was not stencilled to the tail of repainted aircraft. Non-standard markings were applied to some.

      The knowledge and skill of painters, as well as the conditions under which painting is done, vary from good to quite bad. It was possible to hand-peel large sheets of finish from some aircraft.

One appeared to have been painted during a sandstorm. Others showed evidence of high quality work with good surface preparation.

Obviously with this state of affairs, it is not possible to evaluate the performance of finishes in preventing corrosion or maintaining appearance. Moreover, it does not seem useful to apply costly finishes, which are claimed to have a six year service life, when (a) their better qualities have not been proved in service through controlled test and (b) they will be overcoated routinely to maintain appearance.

Variations in washing and cleaning have been noted above. Over-enthusiasm can be a problem, however. We observed one aircraft the inside of which had just been hosed down thoroughly, despite express provisions to the contrary (T.O. 1C-141A-23).

2. Maintenance action reporting and data collection practices affect most directly the value of AFM 66-1 for corrosion tracking and prediction. The most serious problem observed was the widespread use of Support General Work Unit Codes for corrosion maintenance. At some bases, only isolated individual workers followed this practice; at others, none did; at some, everyone was guilty. It would appear that a large volume of corrosion work is undocumented outside of the base. The data would be available to base management for a limited time via BLIS, but force-wide maintenance data products, e.g., 16-LOG-K261 "Work Unit Code Corrosion Summary", would suffer from comparing apples with oranges.

   A related problem, not revealed during our visits but by subsequent analyses of the AFM 66-1 data base, is the fact that there is no uniformity of practice in using the various codes. This problem will be described fully in the Final Report of this Project.

   We believe the major source of difficulties in the data system is the overwhelming volume of documentation which personnel at all levels are expected to read and understand. Human nature being what it is, we doubt whether many people do manage to read all of it.

C. Information on maintenance and Force Utilization Practices. Frequently some difficulty was experienced in acquiring information and, in several cases, information was found to be in error. Although everyone made every effort to cooperate with us, the problems of obtaining information are understandable. In some cases we were unable to explain clearly what we wanted to know, and in other cases we were ignorant of the existence of useful data.

Inaccurate information, however, has been a more serious problem. Again, we feel the root cause to be the overwhelming sea of documentation that even the most dedicated people could not master. Several examples will illustrate the sort of problems encountered.

1. Painting. Information from Warner-Robins ALC and AF documents showed that complete aircraft painting is done only at depot or by specific contractors, and field units do nothing but touch up work. Indeed, we were provided detailed histories of painting of the C-141A Force which we expected to use in relating corrosion damage to utilization and preventive measures. But the very first aircraft examined had been completely repainted, except for the stenciled repaint data on the tail (which corresponded with our records.)

2. Inspection cycles. According to FY 1977 and FY 1975 PDM documents (2,3), the inspection cycles in effect are 15 day Home Station Check, 70-day minor inspection, 140 -day major inspection, 36-month mid-interval, and 36-month PDM. In the field, we learned that this cycle had not been in effect for at least two years and a different cycle was in use which seemed to vary slightly from base-to-base.

3. Dedicated Aircraft. It had seemed reasonable to us to assume that specific aircraft would be used for the same mission over extended time periods. Such would be an efficient use of equipment and personnel. Everyone asked insisted nothing of the sort was done, because change of configuration is quite easy. Yet at the next-to-last base visited, we finally acquired information concerning "diplomatic", "courier", and other such dedicated aircraft. They are not dedicated permanently, of course, but the time periods are long enough to have possible effects on corrosion experience.

4. Field MS vs. Organizational MS. Considerable time was spent interviewing FMS corrosion control personnel. We were surprised, when the Owning Work Center codes were compared with AFM 300-4 (see first paragraph under C. above), to learn that not one corrosion record out of 250,000 records in our data base came from these shops. The great bulk of our records had come from OMS.

   Additional examples have been encountered, but those listed are sufficient for this report.

D. Aircraft Condition - Some Additional Observations.

The following comments mostly are concerned with paint failure modes and conditions.

Normal degradation of paint on the upper wing and fuselage results from exposure to ultraviolet radiation. The paint binder decomposes and erodes away leaving exposed pigment particles ("chalk"). Such decomposition is related directly to exposure time and radiation intensity, although wind, sand, and rain may contribute to the erosion rate. In this degradation mode, the film remains intact and continues to protect the underlying metal; the chalky surface is not regarded as attractive, however. Under mild solar conditions, the probable useful lifetime of the polyurethene/epoxy finish system appears to be five to seven years.

Many examples were observed of severe degradation of paint films on the upper surfaces, where the film suffered a loss of integrity and peeled to expose the metal. The worst such cases were found where the solar exposure was highest. This is abnormal film degradation and, if caused by radiation, it suggests that unsuspected problems may exist with the finish systems. A possibly related observation was the general absence of this form of degradation at Altus, where solar exposure is high but the aircraft carry a film of gypsum from the wash water. Paint which degrades in this way probably has a maximum useful life of two or three years.

Paint films fail mechanically because of flexure. This usually occurs on the fuselage, especially forward of the main landing gear pods and in the general area of the cargo deck. Mechanical flexure appears to fracture

the paint around fasteners as well as loosen fasteners and subsequently fracture the film. Seepage of spilled hydraulic fluid past fasteners may play an active role in the process as well as an unsightly passive role. Once fractured, the corrosion of underlying fastener and skin proceeds rapidly.

As noted elsewhere, a variety of repaint cures are attempted: spot painting around individual fasteners; strip painting along lines of fasteners (connect-the-dots); area painting; complete repainting. Close inspection of fasteners in all cases showed that none are effective in stopping the damage. As far as fasteners are concerned, we suspect that all painting efforts are of little value. If the fasteners are at all loose, then it will be but a short time before the film fails again. Clearly the polyurethane/epoxy system is too brittle for this application.

25,000 lb tie down fittings forward of FS1178 appear to have been reworked on all aircraft. Rearward, however, the condition of these TDF's exhibited several degrees of bad. The problem clearly is aggravated by leaving cargo rails installed for extended time periods and by permitting water to enter (through open doors) and to stand in the area. In a number of aircraft at one base, this corrosion was much more severe on the port side, but equally bad on both sides at most bases.

Conclusions

The present Research Program was begun under the assumption that the extent of aircraft corrosion damage, and hence need for repair, could be explained in terms of the environment. The term "environment" was understood in a very

general sense, including the usual environmental factors such as pollution, wind, moisture, operational factors, and miscellaneous factors such as design, accidents, etc. (4). As a result of our exhaustive analysis of AFM 66-1 and mission profile records for the C-141A Force as well as the trip reported herein, we have matured a great deal in our understanding of the word "environment".

Part of the environment very clearly is the individual base posture toward corrosion maintenance. This is a multidimensional problem, but at least one would include these factors: commitment; facilities; data reporting (paperwork). Assigning a "grade" for these categories - plus (+) for good, minus (-) for not-so-good -- for the six MAC bases visited (without naming names) gives the matrix shown in Figure 1.

What is unfortunate, from our viewpoint, is the fact that these three variables (and more) are part of the inputs to AFM 66-1 data. In our data analyses, we have made a great deal of progress toward identifying where and how some of these factors input the data system. Although there is some possibility of filtering them out ("data massage"), it does not at this time seem possible to do this with existing AFM 66-1 records so that they can be converted into an accurate measure of corrosion experience.

AFM 66-1 is in great need of overhaul, if not outright restructuring, from the ground up. It is redundant, superfluous, ponderous, occasionally both relevant and irrelevant. Objectives of this overhaul should be:

- reduce, if not eliminate, base-to-base variations in maintenance policies and practices;
- drastic reduction in the volume of documentation;
- a clear statement of what Force-wide purpose will be achieved via AFM 66-1;
- effective provision for updating the system so that we shall not again

Figure 1

Approximate base ratings on three parameters

	Base A	Base B	Base C	Base D	Base E	Base F	
COMMITMENT	—	+	+	+	+	— ??	
FACILITIES	+	+	—	+	—	—	
DATA REPORTING	—	—	+	—	+	—	

experience the problems we have today.

We assume, of course, that corrosion would be an integral element of a revised AFM 66-1, with sufficient emphasis on accurate reporting to make corrosion tracking and prediction possible.

Acknowledgements

We wish to thank BGEN E. Nash, Col. A.L. Trott, and Col. M.C. Padden, HQ MAC, for their continuing interest in this program. We are especially appreciative for their efforts to make this trip possible and to have SM SGT E. Smith accompany us.

In addition, we wish to express our thanks here to the many people at the various airbases who did so much to help us, with apologies for an occasionally lost first name:

Norton AFB

Lt. Col. K. Lowrey
CM SGT D. Martin
M SGT. J. Whitten

McChord AFB

Mr. C. Mailand
SGT. R. Shippee
Mr. McVittie
Mr. E.A. Richardson

Travis AFB

Lt. Col. C.H. Reese
Mr. T. Kirkpatrick
C. M SGT. Tucker
M SGT. Mongno

Altus AFB

Col. W.G. Holman
Col. J. Ritenour
Lt. Col. Buckner
Major Clemson
Capt. L. Prose
M SGT. Cook
CM SGT. Perala
CM SST. R. Pearson
Mr. Allen

McGuire AFB

Lt. Col. R. Larsen
Mr. C. Kleinfelder
T. SGT. Hacker

Base Visit Report

Charleston AFB

Col. P.L. Geasland
Lt. Col. Harner
Mr. F. Hogan

Mc Connell AFB

Col. R.L. Jones
Col. J. Hampton

Boeing - Wichita

Mr. J. Wherry
Mr. R. Balbierz
Mr. T. Kozan

RS/po'm
4/26/77

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APPENDIX C

MINOR CORROSION HOW-MALFUNCTION CODES, C-141A MAINTENANCE DATA 4Q70 - 4Q74 INCLUSIVE.

Code	No. Records	Description
410	574	Lack of, or improper lubrication
135	318	Binding, stuck or jammed
301	275	Foreign object damage
878	3	Weather damage
037	220	Fluctuates, unstable or erratic
381	129	Leaking - internal or external
800	428	
799	212	No defect
242	69	Failed to operate or function - specific reason unknown
127	35	Adjustment or alignment improper
105	34	Loose or damaged bolts, nuts, screws, rivets, fasteners, clamps or other common hardware
730	27	Loose
932	34	Does not engage, lock or unlock correctly
020	29	Worn, chafed or frayed
160	24	Contacts/connection defective
130	20	Change of value
425	18	Nicked
150	20	Chattering
901	18	Intermittent
804	26	No defect-removed for scheduled maintenance
246	21	Improper or faulty maintenance
910	11	
780	15	Bent, buckled, collapsed, dented, distorted or twisted

Code	No. Records	Description
615	10	Shorted
008	11	Noisy
374	10	Internal failure
750	7	Missing
070	8	Broken
106	8	Missing bolts, nuts, screws, rivets, fasteners, clamps, or other common hardware
330	4	Excessive hum
007	4	Arcing, arced
958	10	Incorrect display
457	3	Oscillating
108	4	Broken, faulty or missing safety wire or key
290	4	Fails diagnostic/automatic test
651	3	Air in system
660	1	Stripped
240	2	?
690	3	Vibration excessive
803	2	No defect-removed for time change
111	2	Burst or ruptured
710	2	Bearing failure or faulty
001	1	Gassy
525	3	Pressure incorrect
567	1	Resistance incorrect
303	2	Bird strike damage
010	1	Poor or incorrect focus
805	1	No defect-not otherwise coded etc. (catchall)

Code	No. Records	Description
080	1	Burned out or defective lamp, meter or indicating device
711	1	Improper blanking
982	1	Frozen tuning mechanism
653	1	Ground speed error excessive
540	1	Punctured
561	1	Unable to adjust to limits
300	1	Grounded electrically
625	1	Gating incorrect
383	2	Lock on malfunction
025	5	Capacitance incorrect
503	2	Sudden stop
177	1	Fuel flow incorrect
255	1	No output/output incorrect
947	1	Torn
720	1	Brush failure/worn excessively
669	1	Potting material melting
900	1	Burned or overheated
167	1	Torque incorrect
812	1	No defects - indicated defect caused by associated equipment malfunction
103	1	Attack display malfunction
935	16	Scored or scratched
602	2	Failed or damaged due to malfunction of associated equipment or item
	2708	

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